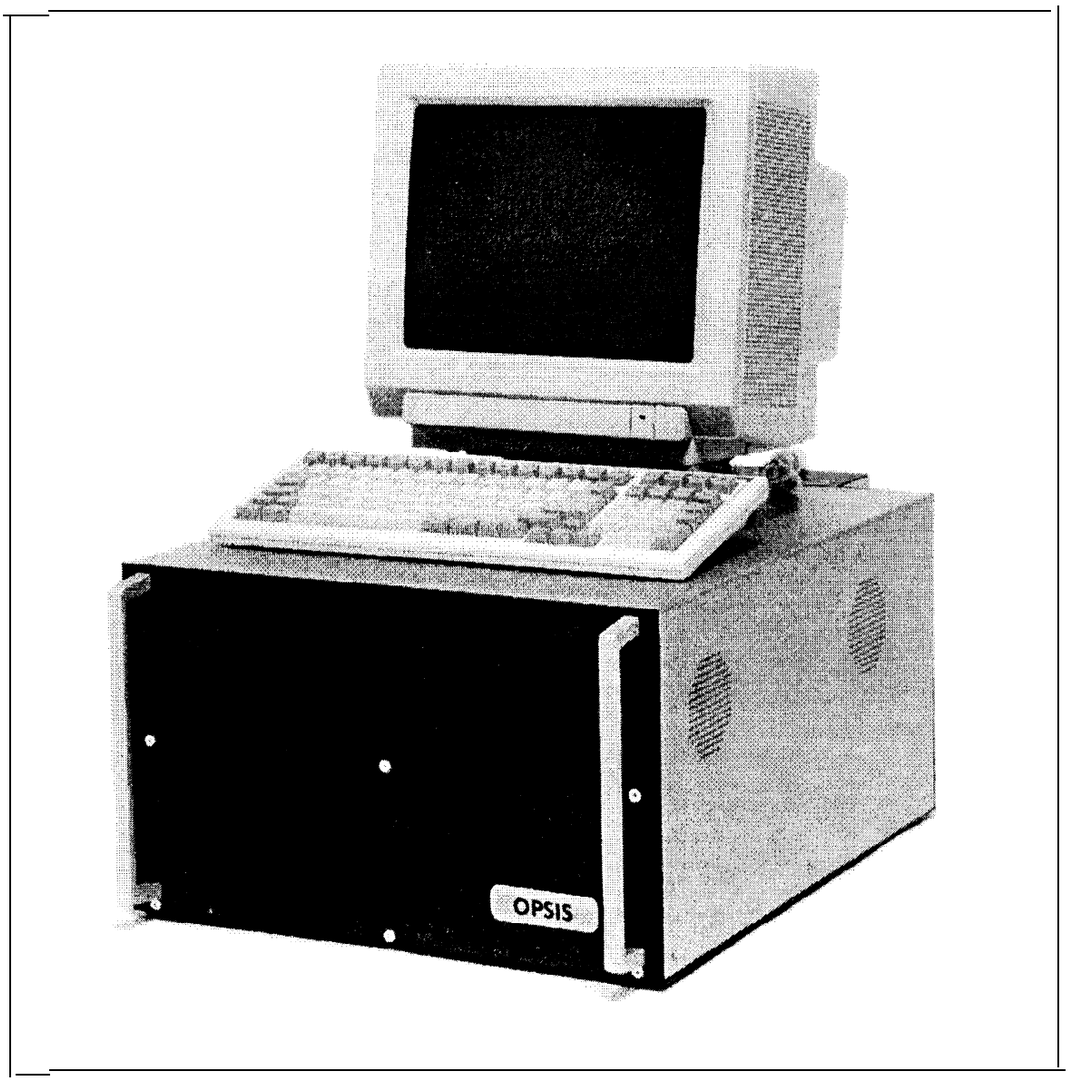
OPSIS®



OPTO-ANALYSER AR 500

FOR

AIR QUALITY MONITORING

HARDWARE OPERATINGMANUAL

CONTENTS

1. INTRODUCTION

The opto-analyser AR 500 is the central unit in the AR 500 air quality monitoring system. The **AR** 500 is responsible for the evaluation and the storage of all results.

This manual contains information on the analyser hardware, physical specifications, setup instructions, calibration descriptions, maintenance and troubleshooting schemes.

For the analyser software, the **OPSIS** program, please refer to the analyser software manual.

UL listing covers the AR 500 analyser only. Other accessories mentioned in this manual have not been evaluated.

1.1 THEORY OF OPERATION

1.1.1 The monitoring path

The positioning of the emitter and the receiver define the monitoring path. The light source in the emitter is a high-pressure xenon lamp. This type of light source radiates an almost smooth spectrum ranging from approximately 200 nm up to 500 nm, where a number of gaseous substances show specific absorption spectra.

The emitted light beam is directed towards the receiver, and on its way through the atmosphere the intensity is affected by scattering and absorption in molecules and particles.

From the receiver the captured light is led via an opto-fibre to the analyser. The function of the fibre is only to avoid exposing the opto-analyser to bad weather, temperature variations, etc.

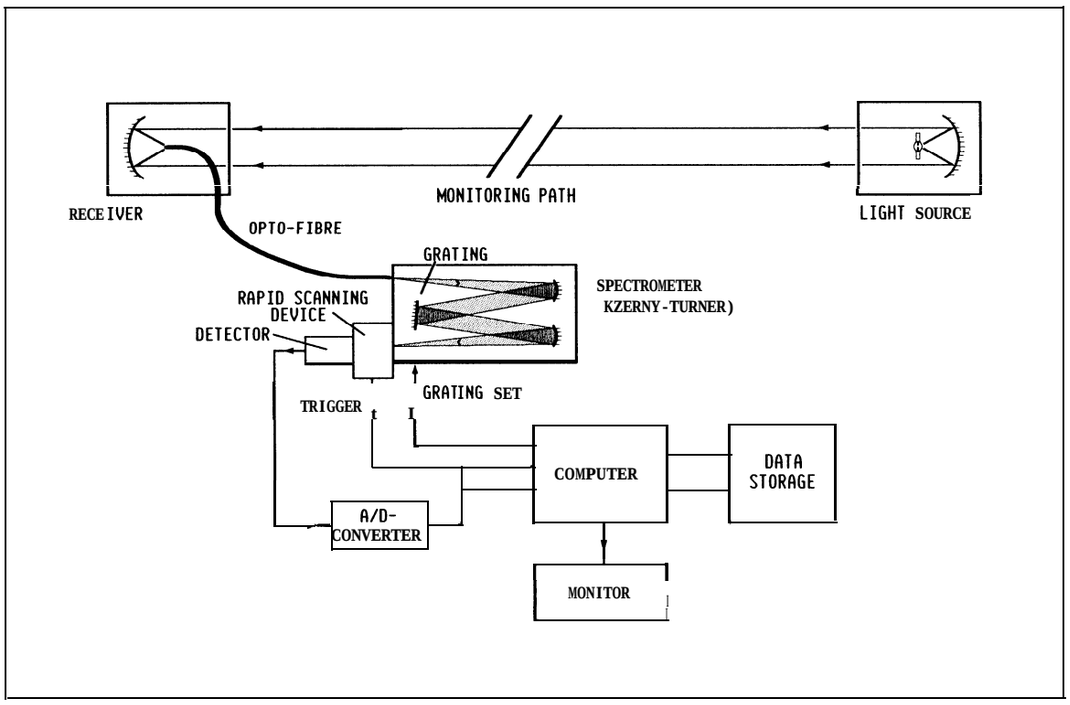


Fig. 1.1 An Opsis system consists of a light source, a receiver, an opto-fibre, and an opto-analyser. The analyser consists of a spectrometer, a detection system, electronics for the operation of the grating, the detection system, etc., and a computer for the evaluation and signal processing.

1.1.2 The opto-analyser

When the light reaches the analyser, it enters a spectrometer. Inside the spectrometer, a grating refracts the light into its wavelength components. The refracted light is then projected onto a rapid scanning slit in front of a photo-multiplier detector, where a selected part of the spectrum is detected. The scanning slit device makes it possible to record all wavelengths separately, although only one detector is used.

As the grating is moveable, any chosen part of the spectrum can be detected. The wavelength window can thus be optimized for a certain component, with respect to parameters such as sensitivity and interfering pollutants. Approximately 100 scans per second are recorded.

The current from the detector is converted into digital signals by a 12 bit analogue-to-digital converter, and the signal is stored and accumulated in a multi-channel register. The detected spectrum is typically 40 nm wide, and each scan is digitized into 1000 points.

Each pollutant is monitored during a time period entered by the operator. When the data accumulation is finished, the evaluation process is started. At the same time the next data accumulation period starts.

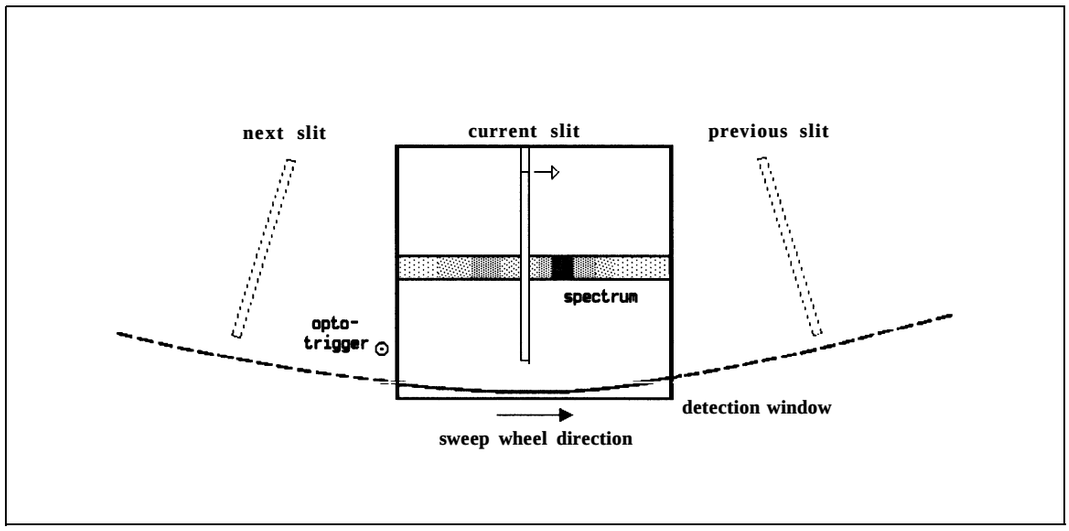


Fig. 1.2 Schematic drawing of the exit window and the scanning slit in the spectrometer. The detector's "eye" covers the whole window.

Due to turbulence in the air the recording time for one spectrum has to be in the order of 10 ms. A fixed slit is thus not applicable. A slotted disk, rotating with about 300 rpm, provides the detection system with the required time resolution.

The opto-trigger signal is used by the computer to prepare the multi-channel memory for a new scan, and to reset the analogue-to-digital converter.

1.1.3 The technique

As no reference level of the emitted light can be taken, like in, for instance, a conventional ozone monitoring instrument based on the UV-absorption technique, the total light intensity at the receiver has to be made insignificant.

Important information on the gas content in the atmosphere is hidden in the tiny narrowband pattern in the spectrum. This pattern is named differential absorption. The broadband absorption is impossible to differentiate from, for instance, water vapour absorption and scattering against particles, and can therefore not be used in the evaluation.

The evaluation is based on Beer-Lambert's law

$$I_1 = I_0 e^{-c\alpha_1 l} \qquad [1.1]$$

The law gives the relation between the light intensities before and after the sample, as functions of the molecular concentration of a gas c, the sample length l, and the absorption coefficient α_1 at the wavelength λ_1.

The absorption coefficient varies with the wavelength of the light and quantifies the probability for light absorption at each wavelength. It is expressed in units of [m^2 per molecule], [m^2 per μg], or something similar, depending on the unit of the concentration. The absorption coefficient can thus be treated as an area, and another denomination for a is cross-section.

Beer-Lambert at the wavelength λ_2 is written as

$$I_2 = I_0 e^{-c\alpha_2 l} \qquad [1.2]$$

By calculating the ratio of the expressions [1.1] and [1.2], and taking the logarithm of I_1/I_2 the result is

$$\ln \frac{I_2}{I_1} = c\,(\alpha_1 - \alpha_2)\,l \qquad [1.3]$$

The reference light level I_0 is thus eliminated, and the gas concentration c is possible to evaluate by measuring and calculating the differential light level I_2 / I_1, and taking the differential cross-section ha into account. The ratio between the intensities is inverted in order to avoid a negative expression to the right of the equals sign.

The differential cross-section curve within the current wavelength window is stored in a data library, together will all interferant cross-sections.

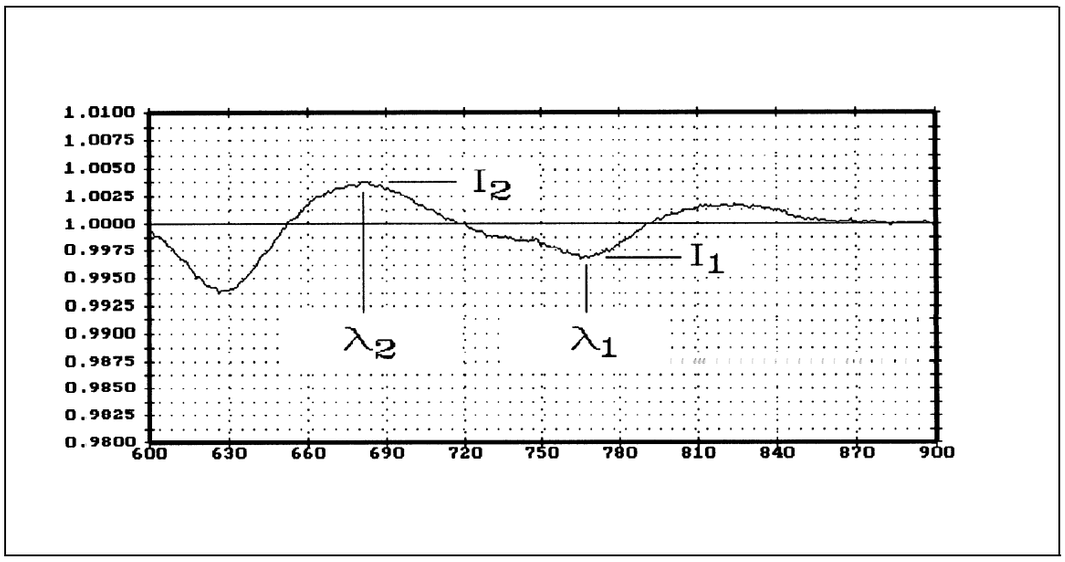


Fig. 1.3 Graphic presentation of the differential absorption. The influence from the lamp and the broadband absorption are eliminated. Assuming the absorption is originating from one component only, the unknown concentration c can be calculated from the ratio I_2/I_1, following equation **[1.3].** The cross-sections α_1 and α_2 at the wavelengths λ_1 and λ_2, respectively, must be determined on forehand. The result is always a mean value taken over the monitoring path length l.

1.1.4 The evaluation

The digitized spectrum, which is stored in the multi-channel memory, consists of 1000 data points. In the first step of the evaluation the absorption spectrum is corrected for the small spectral variations in the lamp output. The xenon lamp spectrum is pre-recorded under circumstances where no absorption for the gases in measurement was present. The lamp spectrum can thus be treated as a zero-point spectrum.

The absorption spectrum is divided by the lamp spectrum and the result is a raw spectrum for further treatment.

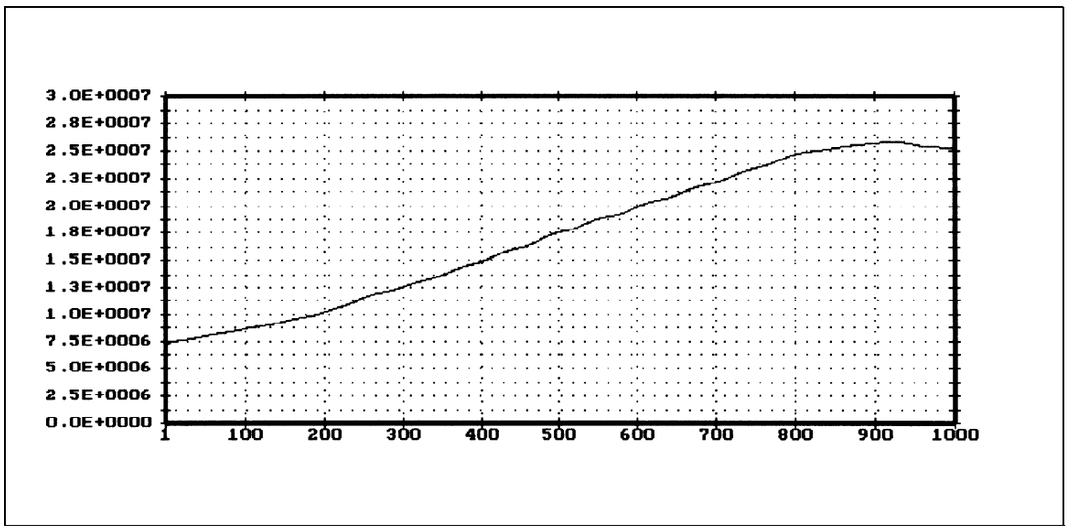


Fig. 1.4 The absorption spectrum. This example is recorded with the centre wavelength at 300 nm.

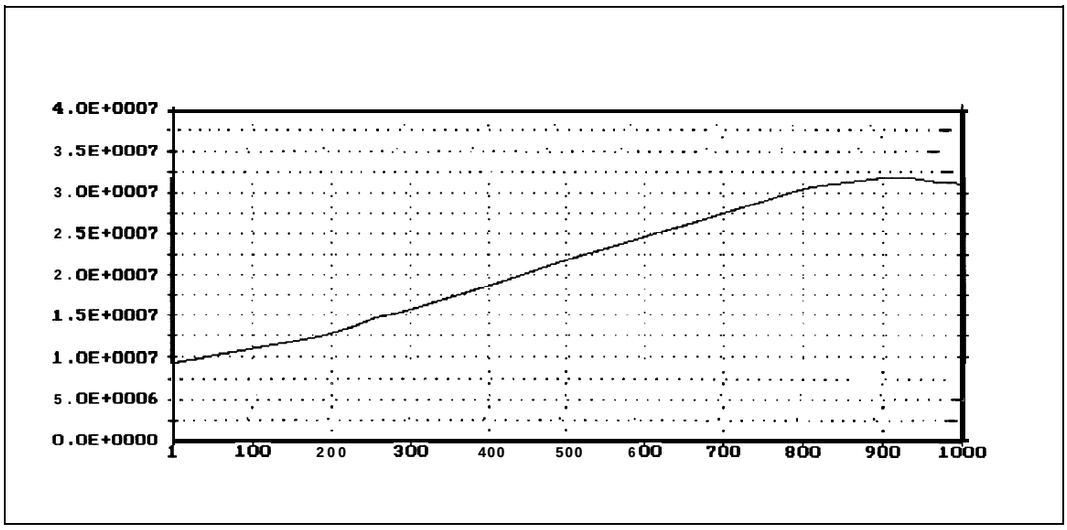


Fig. 1.5 The lamp spectrum, recorded at zero-gas conditions.

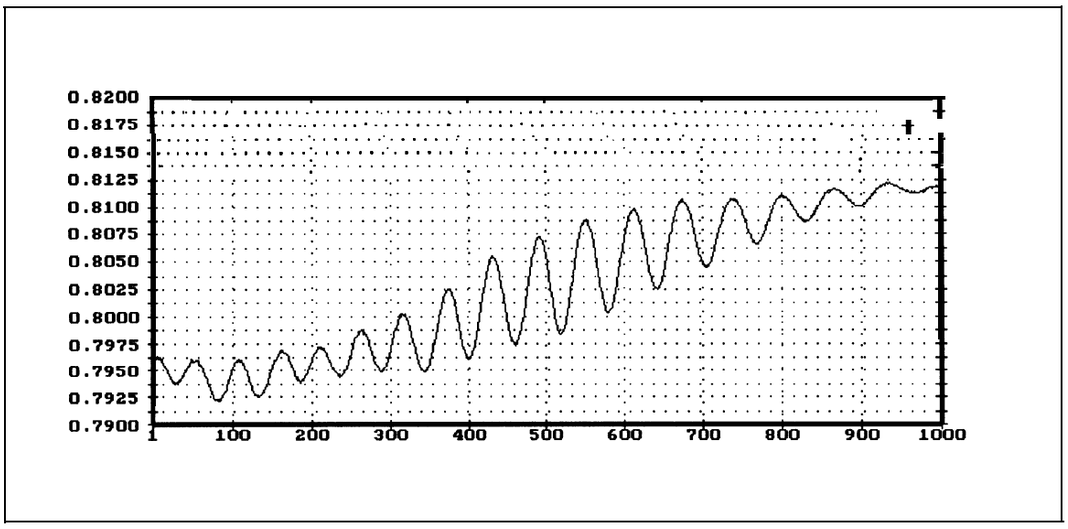


Fig. 1.6 The absorption spectrum divided by the lamp spectrum results in a raw spectrum, which shows the total absorption, i.e. the sum of broadband and the differential absorptions.

In the second step the broadband absorption is to be eliminated. In this step an assumption is made; as the broadband absorption shows no narrowband structure it can be approximated with a polynomial. A polynomial of adequate degree is therefore fitted onto the raw spectrum. When the ratio is calculated the broadband absorption has been removed. The remaining narrowband structure is the differential absorption, on which the succeeding calculations are based.

The degree of the polynomial must not be too high, as it will then fit also to the narrowband absorption, and valuable information in the signal may be lost. The degree is usually set to 5.

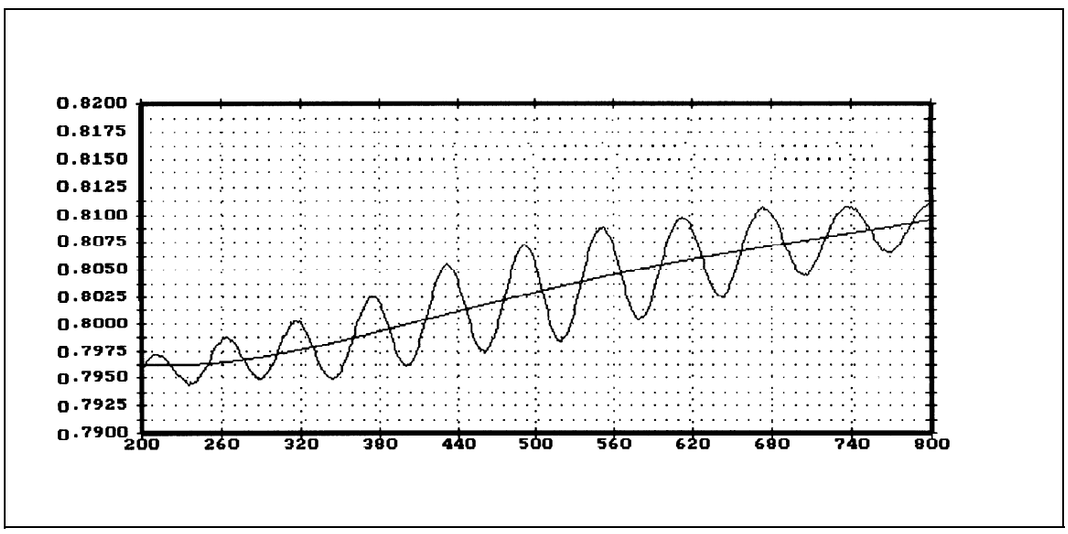


Fig. 1.7 The raw spectrum, where the fitting of a fifth degree polynomial is shown. The polynomial represents the broadband absorption.

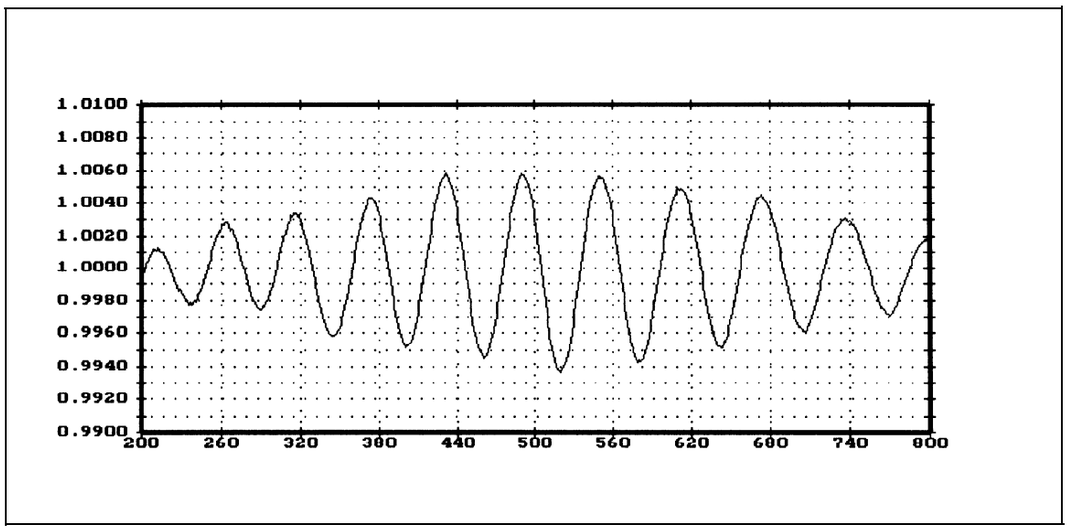


Fig. 1.8 The result, when the raw spectrum has been divided by the polynomial. This is the differential absorption spectrum from the atmospheric gases

The result is now a differential absorption spectrum, which contains “fingerprints” from all gases in the atmosphere between the emitter and the receiver. A mathematical absorption spectrum made of the pre-recorded cross-section spectra is now developed, so that the fitting to the measured absorption spectrum is as good as possible. This is done with a least-squares fit, and from the result the unknown concentrations are calculated.

The quality of the result is estimated by investigating the residual area between the fitted and the measured spectra. The presented standard deviation is the standard error of the fitting, which includes noise, unknown interferants, etc., weighted for respective cross-section.

Due to mechanical inaccuracy, the grating will most likely not be able to find exactly the same position from time to time. A correction for this has to be made. This is done by repeating the calculations in the evaluations 21 times, with a shift of 1 channel, i.e. 0.04 nm, between each. A channel range of ± 10 is then covered. The correlation, which is another parameter proportional to the residual area from the fitting, is compared for the 21 results. The final result is taken where the correlation was found to be the best.

Finally, the result is corrected arithmetically for the operator-defined span and offset factors and also for current pressure and temperature. The result is then stored on the disk memory, together with standard deviation, light level, date and time.

The parameter light level is taken from the voltage, which controlls the detector amplification. A low light intensity is compensated by a high amplification, and the light level is then set to a low value, and vice versa.

2. HARDWARE

2.1 SPECIFICATIONS

The specifications are typical for air quality monitoring.

Substances	**NO2** SO_2 O_3
Measurement range	0 - 500 ppb
Minimum detectable concentration	
(measurement path 20 metres, monitoring time 60 seconds)	10 ppb
(measurement path 500 metres, monitoring time 60 seconds)	1 ppb
Calibrations	
Reference (zero-point) calibration	Once a month (using an Opsis CB 100 setup)
Other calibrations	A function check using standard a gas should be made once every third month.
Recommended measurement time	60 seconds/substance
Measurement time for operation under EPA equivalent method designation	**30** to 120 seconds
Maximum measurement cycle time for operation under EPA equivalent method designation	200 seconds (3 minutes 20 seconds)
Recommended path length	**300 – 800** m
Path length for operation under EPA equivalent method designation	20 – 1000 m for SO2 and 03, 50 – 1000 metres for NO2

(For other gases and/or applications than the above, other specifications are available.)

⇒

Hard disk memory	120 Mbytes, or more.
Floppy disk drive	3 1/2", 1.44 Mbytes
Modem	Hayes-compatible, 14400 baud, full duplex
Power supply, consumption	230 VAC (+ 6%, -10%), 110 W, or 115 VAC (±10%), 110 W
Dimensions (L x W x H)	600 x 440 x 266 mm^3
Weight	Approx. 30 kg
Degree of protection	IP 20
Temperature range	
Storage	±0 to 45°C
Operating	+5 to 30°C
EPA equivalency	+ 20 to 30°C
Humidity range	0 to 80% relative humidity, non-condensing

2.2 INSTRUMENT HOUSING

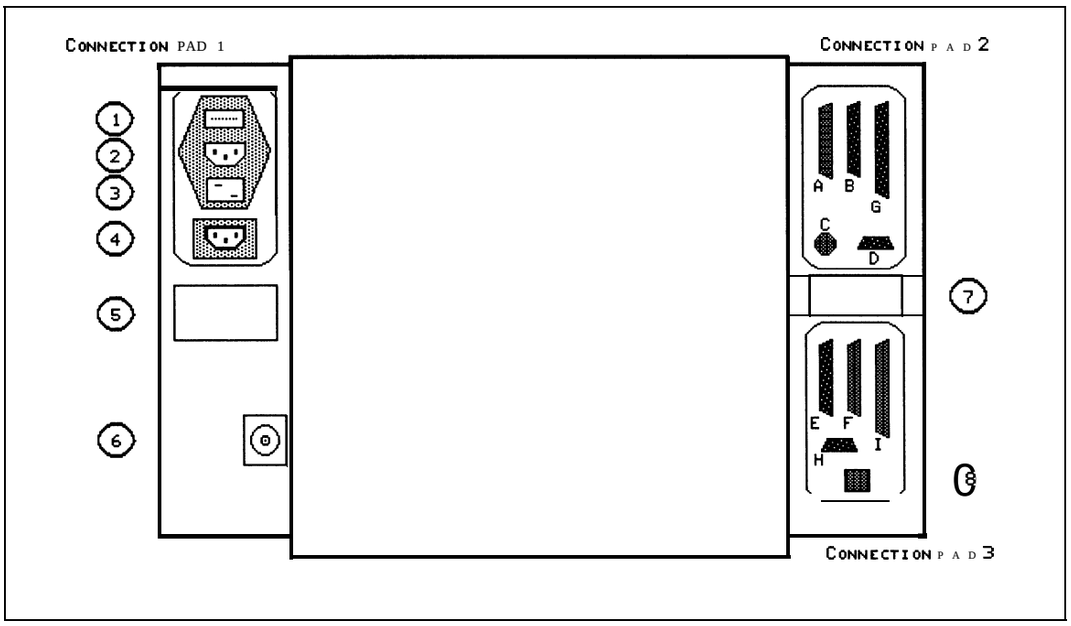


Fig. 2.1 Analyser housing, rear view.

1. Mains power on/off.
2. Mains input.
3. Fuse holder, 115/230 V programmable.
   110 – 120 V AC: 5A SLOW/250V (xl);
   see the figure for the correct position.
   220 – 240 V AC: 2.5A SLOW/250V (x2).
4. Power outlet for monitor.
5. Warning sign.
6. Fibre optic connector.
7. Type/serial number label.
8. Telephone connector RJ11 for modem, COM1.

A. Serial port RS-232C, COM2. For connection to:
   external modem / short haul modem (optional)
   datalogger DL 010 (optional).

B. Parallel printer port.
C. Keyboard connector.
D. Output connector for monitor.
E. Analogue current output (optional)
F. ER 130 interface (optional) or extra RS-232C serial port (optional).
G. Not used.
H. MX 004 / MX 012 / MX 024 / CA 004 output connector.
I. Connector to datalogger DL 016 (optional).

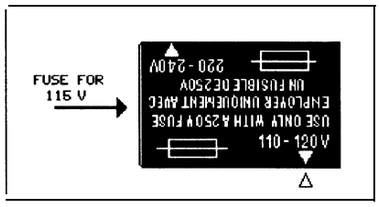
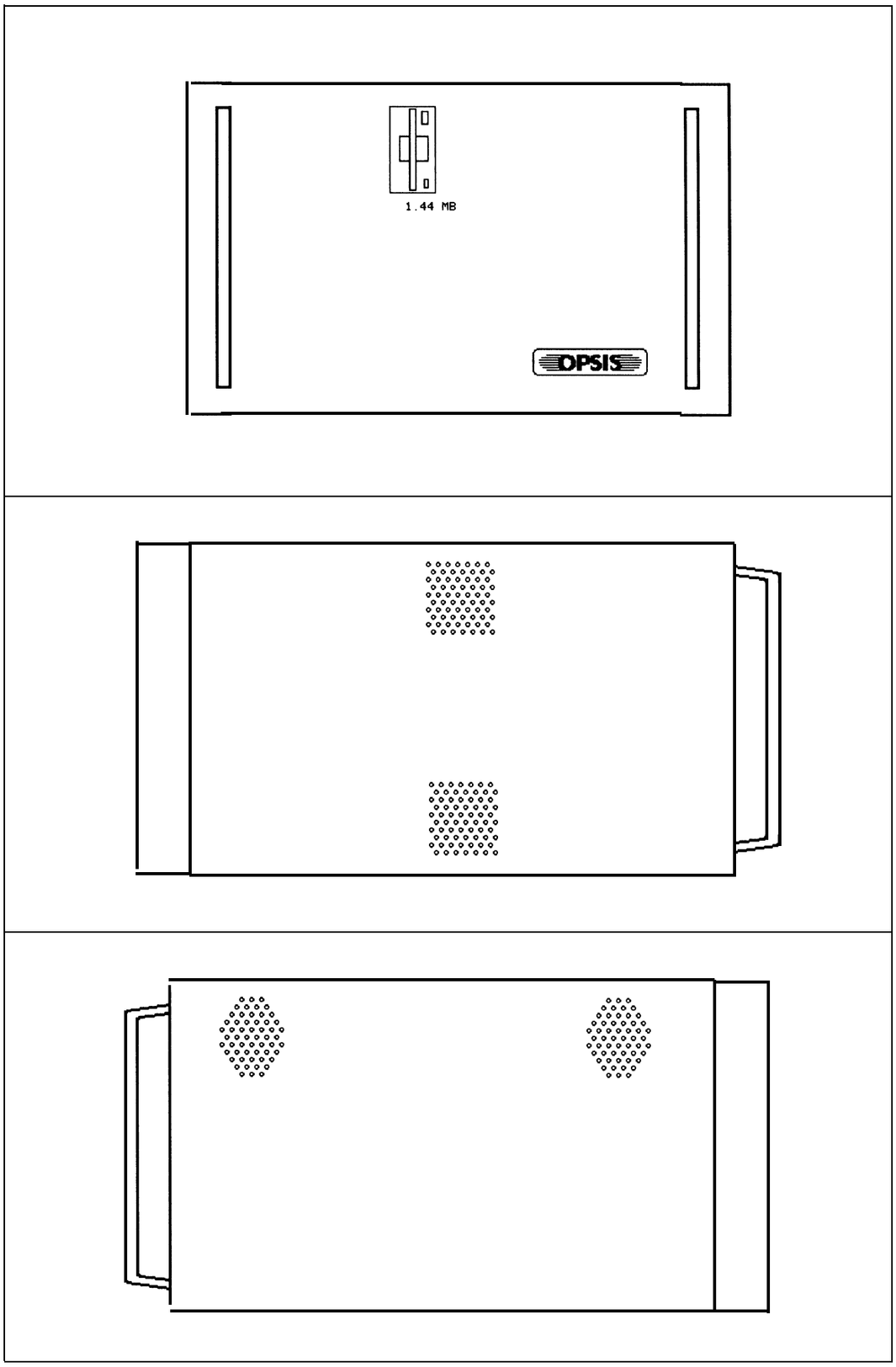


Fig.22 Fuse holder, here set at 115 V mains supply.



Figs. 2.3, 2.4 and **2.5** The front side with the floppy disk drive (top), left and right side.

2.3 COMPONENT LAYOUT

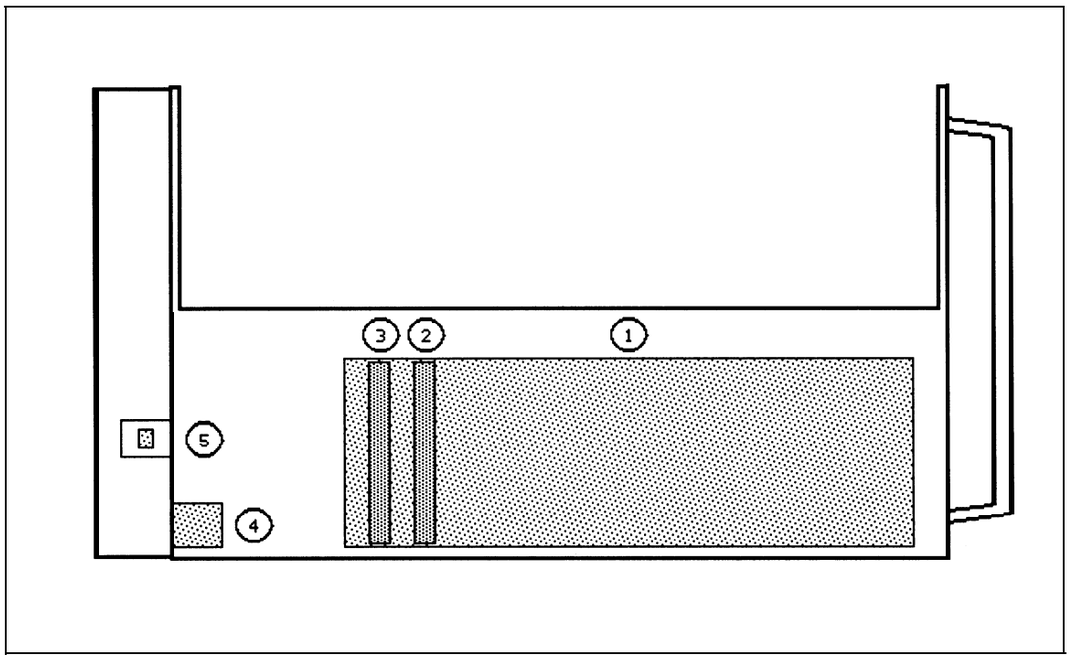


Fig. 2.6 Component layout, lower deck (side view).

1. Rack for eurocards.
2. Photomultiplier voltage control card – PMT-VC (1 - 3 pcs).
3. Analogue to digital conversion card – A/D-2 (1 - 3 pcs).
4. Modem overvoltage protection card – MVF!
5. Sweep trig cards.

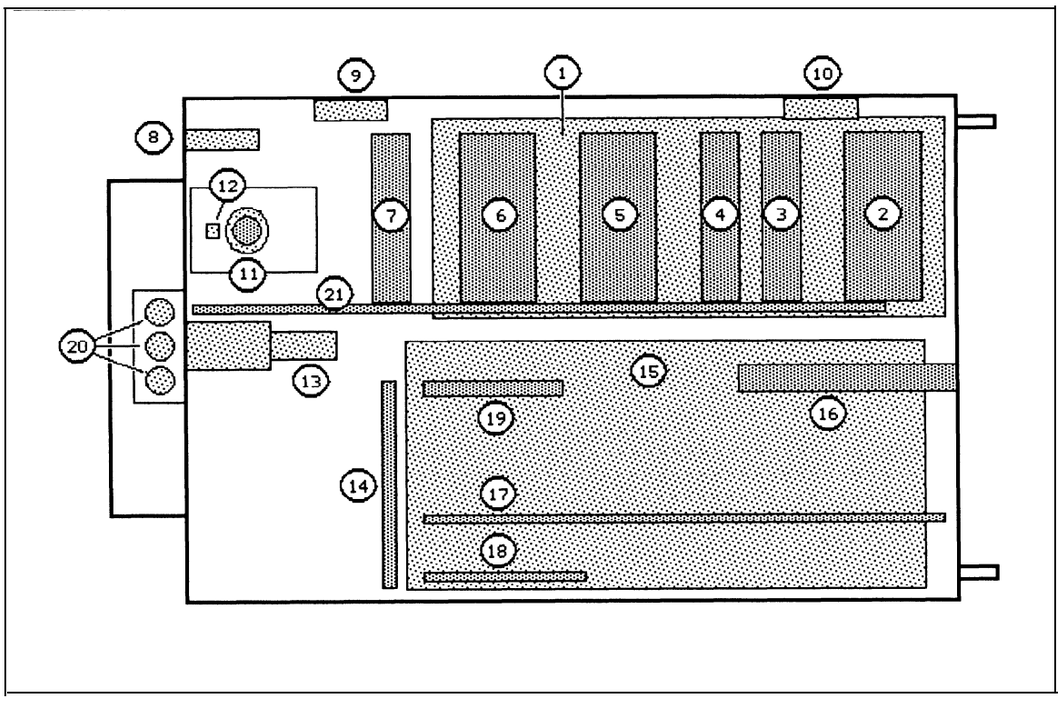


Fig. 2.7 Component layout, upper deck (top view).

1. Rack for eurocards.
2. Power module 0 – PMO.
3. Power module 1 – PM1.
4. Power module 2 – PM2.
5. Sweep motor drive – PFC.
6. Grating motor drive – D631.
7. Hard disk.
8. Mains filter.
9. Fan.
10. Fan.
11. Grating motor.
12. Grating trig card.
13. Sweep motor.
14. Adapter holder.
15. PC main board.
16. Floppy disk drive.
17. Co186 card (1 - 3 pcs.).
18. Graphics display adapter.
19. Modem.
20. Photomultiplier and high voltage power base (1 - 3 pcs.).
21. Interconnection card – BP1

Optional adaptors: Datalogger card – DL 016
Analogue and digital input and output signal cards – AO 008, AI 016 resp. DI 032
Co486 speed card

2.4 FUSES

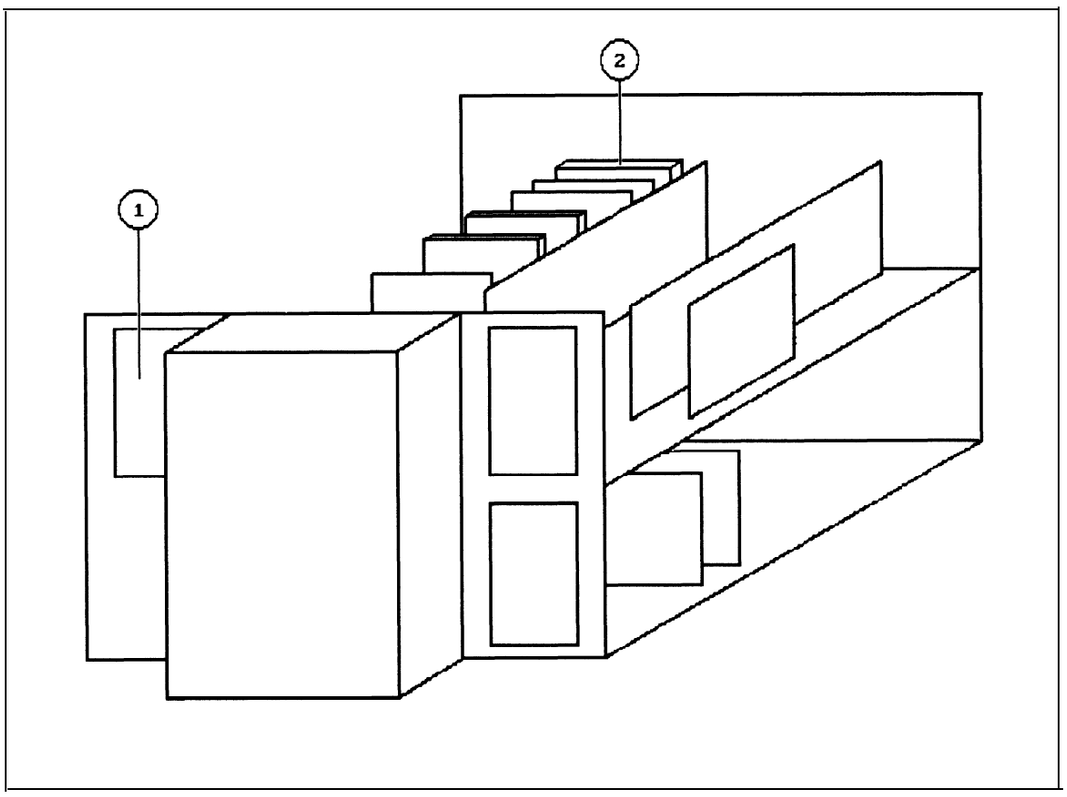


Fig. 2.8 Fuse locations.

WARNING - for continued protection against risk of fire, replace only with fuse of the specified type and current ratings.

Note that the protective housing of the instrument may only be opened by authorized service personnel.

European version (230VAC, + 6%, -10%):

1.	Fuse socket	2 x 2.5A SLOW / 250V
2.	Power module 0 – PM0	1 x 8A SLOW / 250V (size 5 x 20 mm)

U.S. version (115 VAC, ± 10%):

1:	Fuse socket	1 x 5A SLOW / 250V
2.	Power module 0 – PM0	1 x 8A SLOW / 250V (size 6.3 x 35 mm)

3. SAFETY PRECAUTIONS

3.1 WARNING

- The keyboard and monitor comprise the only user interface with the analyser. The protective housing may be removed ONLY by authorized service personnel. The photo-multiplier and other units are powered by high voltage and any attempt to access these units may result in loss of life.

- Power should always be switched off before adjusting the intensity of the light from the transmitter or connecting a new measurement path. Do not switch on power again until all adjustments have been completed. Failure to observe this precaution may result in permanent damage to the detector.

- DO NOT under any circumstances open or loosen doors or covers which protect the optical units. All such doors and covers are coloured yellow, or bear warning labels. Failure to observe this precaution will void the factory warranty for the instrument.

- WARNING. Before installation, make sure the input voltage selection plug is correct (115 V or 230 V). Also check that the fuse(s) is the appropriate one(s).

Note that the inlet voltage setting may be changed by authorized service personnel only.

3.2 SAFETY PRECAUTIONS FOR THE ANALYSER

Do not open the protective housing of the instrument. This may only be done by authorized service personnel.

- The instrument should be connected to a 230 VAC or a 115 VAC external power supply. The power requirement for the analyser is approximately 110 W, and for a xenon lamp power supply, model PS 150, about 220 W.
- The analyser should be installed on a flat, stable surface.
- Do not position the instrument close to radiators, heating elements or ventilation blowers. Do not expose the instrument to direct sunlight or to dust, moisture, rain or physical impact.
- Do not position the instrument in the vicinity of strong electrical or magnetic fields.
- Avoid exposing the instrument to rapid temperature fluctuations. The recommended operating temperature is +5° to +25°C **and should in no case exceed + 30°C!**
- Avoid exposing the instrument to physical shocks and/or vibrations. This is particularly important when the analyser is in operation.
- Make sure to switch off electrical power **before** connecting or disconnecting cables and/or contacts. This applies to the monitor as well - but not to the keyboard.
- Make sure to switch off electrical power **before** connecting or disconnecting fiber-optic cables.
- Avoid switching on a xenon lamp, which is connected to the same mains plug as the analyser, when the analyser is running.

3.3 SAFETY PRECAUTIONS FOR CALIBRATION GASES

The span calibration procedures require handling of gases and substances which are toxic. Good knowledge is required about their handling!

IMPORTANT! Before handling any gas, always study the supplier's safety instructions and the regulations carefully.

- Gas cylinders must be prevented from falling by means of chains.
- The cylinders should be stored in ventilated, specially provided, storage areas. Toxic gases should be handled preferably outside the workshop or the laboratory. Small quantities can be handled inside a building, under a well ventilated hood.
- All fitting parts must be in good condition. A pressure regulator must be inserted between the cylinder and the unit employing the gas. This function should not be performed by simply throttling the gas through a partly opened valve.

It is important that the gas calibration system is vented to the outside! Also make sure that the gas system is free from leaks.

4 STARTUP AND OPERATION

The analyser AR 500 startup and operation instructions are described in detail in this section. It is also necessary that the former sections and the other hardware manuals are read and understood thoroughly prior to startup operation. The analyser software is described in a separate manual.

4.1 INITIAL POWER-OFF INSPECTION AND PREPARATIONS

To avoid instrument damage, it is important that the user perform a pre-startup inspection of the instrument. The following items should be checked for and, if necessary, be corrected for, with the power OFE

- When installing the instrument, the instructions given in section 3.2, Safety precautions for the analyser, should be followed. If required, the analyser should be mounted in a temperature controlled cabinet in order to protect the instrument from a rough environment.
- Loose or missing electrical connections or circuit boards, or broken items; plugs, screws, etc.
- No loose screws, bits of wire, dirt, etc., are present.
- The correct fuse(s) (1 x 5A / 250V for 115 VAC, or 2 x 2.5A / 250V for 230 VAC) is securely in place in the fuse socket.
- Connect the cables to the keyboard, the monitor and the possible optional equipment; multiplexer, datalogger, etc.
- Check that the transmitter and the receiver are correctly positioned. Connect the fiber-optic cable between the receiver and the central unit. See also the separate manual for the emitter/receiver units.

4.2 INITIAL POWER-ON TESTS

The optimal temperature for ensuring proper operation of the computer is between + 15” to + 25°C. If the instrument has been exposed to temperatures below 15°C, allow it to warm up to room temperature before switching on the instrument.

- Plug in the analyser to a grounded power outlet of the appropriate power rating for your instrument.
- Switch on power. The fans should be heard to indicate that the power is on. Refer to the Troubleshooting section if nothing happens.
- The computer will now start. A sign-on message is displayed for about 20 seconds, after which the screen will show the following:

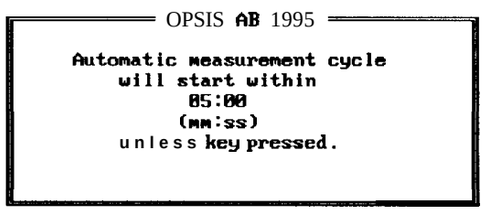


Fig. 4.1 The "warming up" message.

- If any of the installation parameters have to be changed (path length, time settings, etc.), press the spacebar and proceed into the **Installation** menu. All changes of the installation parameters are made via the ANALYSER ROOT MENU (see the analyser software manual). If no key is pressed, the measurements will be automatically started after a warm-up period of about 5 minutes.
- Allow at least 5 minutes for warm-up before proceeding.
- Activate **Optimize light** in the **Installation** menu. The result should be a number between 0.5 and 95%. If no value is obtained, or the value is outside the limits, first check that the opto-fibre is properly connected on the rear side and that light is reaching the analyser. If the value still is improper, proceed into the Troubleshooting section.
- Check the analyser hardware by making a **System check** (see section 6.2). If any of the five parameter values is outside the permissible limits, please refer to the Troubleshooting section.
- Before the analyser is switched into the automatic measurement mode, a reference calibration should be performed (see section 5 for details).

5. CALIBRATION

This section contains descriptions on straigh forward, manually performed calibrations of the analyser. This means that the span calibrations are made via the ordinary measurement mode.

Please note that in the analyser software manual there are alternative-descriptions of the calibration procedures. They are based on the software controlled automatic calibrations which are utilizing the specific calibration menus in the programme.

The analyser contains a spectrometer which is highly sensitive to vibrations, temperature fluctuations and other external conditions. The instrument should therefore be reference calibrated at regular intervals to eliminate the measurement errors that may arise from e.g. a grain of dust in the detector. Reference calibration (zero-point calibration) involves recording the performance of the instrument with light that is introduced directly to the input of the spectrometer. The Opsis CA 150 calibration unit and the CB 100 setup is used for this purpose.

It is important that the operator has read the sections 2 through 4 of this manual, performing all the steps necessary for proper setup and initial checkout of the instrument as specified in those sections, before proceeding to calibrate the analyser.

- IMPORTANT! Before handling any calibration gas, always study the supplier’s safety instructions and the regulations carefully.
- Gas cylinders must be prevented from falling by means of chains.
- The cylinders should be stored in ventilated, specially provided, storage areas. Toxic gases should be handled preferably outside the workshop or the laboratory. Small quantities can be handled inside a building, under a well ventilated hood.
- All fitting parts must be in good condition. A pressure regulator must be inserted between the cylinder and the unit employing the gas. This function should not be performed by simply throttling the gas through a partly opened valve.
- It is important that the gas calibration system is vented to the outside! Also make sure that the gas system is free from leaks.

5.1 REQUIRED EQUIPMENT AND GAS STANDARDS

A calibration system containing a cylinder gas delivery system for SO_2, N02, and possibly other gases, an ozone source for ozone calibrations, and a variable source of clean zero air for the dilution of the span gas sources is necessary. As an alternative to the dilution system a set of calibration cells with different lengths can be used. The system must be able to deliver a minimum of 0.5 l/min.

All fittings, valves, pneumatic lines, and other components that may contact the span test gas must be fabricated or coated with cleaned TFE, FEP or glass.

The SO2 and NO2 calibration gas source standards should be traceable to National Institute of Standards and Technology (NIST) (former National Bureau of Standards, NBS), Standard Reference Material (SRM) or Certified Reference Material (CRM) in accordance with EPA's protocol No. 2.

The use of the Opsis AR 500 analyser for ozone monitoring under EPA designation as an equivalent method requires dynamic calibration with an ozone standard. The dynamic calibration must be performed in strict accordance with the procedures outlined in title 40, Code of Federal Regulations, Part 50, Appendix D.

Dynamic instrument calibrations of ozone are based on a reliable, powerful and variable ozone source, such as the Opsis OC 500 unit. This unit, which is based on a high-frequency electric field, is able to generate several thousands ppm of ozone at a flow rate of 0.5 l/min. In order to avoid any impurities of nitric oxides the source gas should be 100% oxygen.

The ozone standard must be assayed after the generation with a primary ozone standard. Since the accuracy of photometric instruments to assay high concentrations of ozone (over 3 ppm) cannot be verified by comparison with an NIST/EPA Standard Reference Photometer an apparatus for quantitative dilution of the high ozone calibration concentrations to ambient levels has to be employed upstreams the photometer.

Zero air used for the dilution of the standard gas concentrations should contain less than 0.001 ppm of the gas in test.

5.2 REFERENCE CALIBRATION

A reference calibration means that the system response is recorded at zero gas conditions and is stored for future use in the evaluations. Reference calibrations have to be made for each one of the pollutants being measured. However, when two, or more, pollutants are evaluated simultaneously by the analyser, only one reference calibration is required for that set of pollutants. Please see the Analyser Software manual, section 2.2.3, for further explanations.

The rule of thumb for the reference calibration is that the outside measurements should be simulated regarding the light level, however, under zero gas conditions. The reference calibration requires a separate light source and an optical bench for the alignment, see the hardware requirements below.

Reference calibration should be performed:

- After initial installation and all systems operational checks have been performed.
- After any major repairs and/or maintenance occurs.
- After the analyser has been moved or otherwise exposed to vibration.
- If the analyser's zero response deviates more than ±0.025 ppm from zero (EPA requirement only).
- Once a month under normal conditions.

When measuring low ambient concentrations, close to the specified detection limit for the instrument, or when the standard deviations for the measurements tend to increase, reference calibrations may have to be performed two or three times a month.

The detection limit of the analyser is approximately twice the standard deviation registered for a specific measurement.

52.1 Hardware requirements

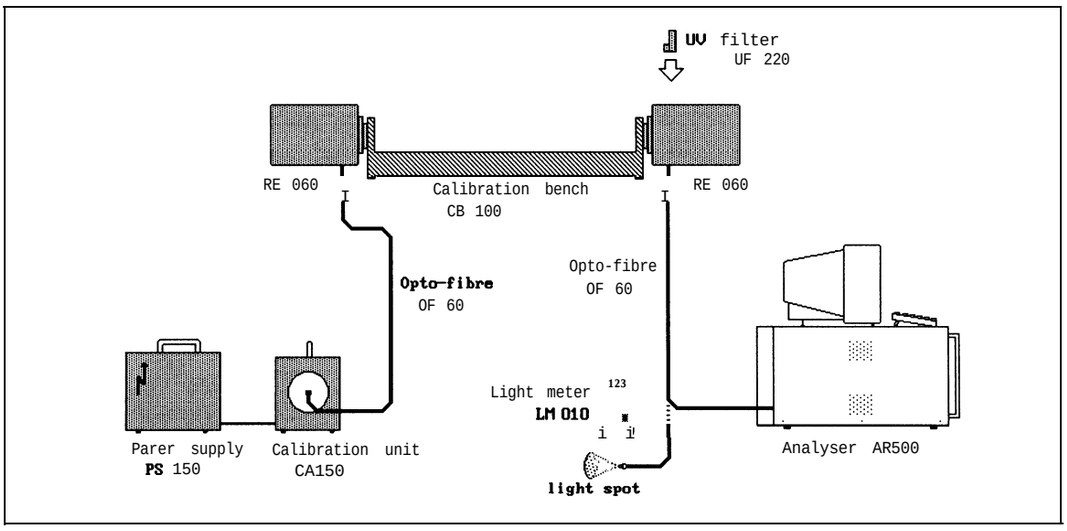


Fig. 5.1 Standard setup for the reference calibration. The UF 220 filter is required only when NO and/or NH_3 is active, see below.

The following Opsis hardware is required for performing the reference calibration:

- Mercury lamp CA 004 for grating setting accuracy check.
- Calibration bench CB 100 and two RE 060 units.
- Lamp unit CA 150, provided with the correct lamp, see table below.
- Power supply PS 150.
- Opto-fibre, two pieces, 3 to 5 metres each, see table below.
- Light meter LM 010.
- Calibration cell CC 001-900 and a zero air source. *

	SO_2, NO_2, formaldehyde and others	ozone, benzene, toluene, xylene	NO and NH3
Opto-fibre	OF 60-S or -R	OF 60-S or -R	OF 60-R
Xenon lamp	Type A or B	Type B	Type A
UV filter UF 220	–		yes

Table 5.1

*) At normal indoor conditions zero air is not necessary since the outside path is typically at least 200 times longer than the CB 100. However, high indoor pollution levels, or very short measurement paths, require a sealed reference path at which the cell and the zero air source have to be used.

5.2.2 Reference calibration performance

The procedure is as follows.

1. Interrupt the measurement mode by pressing **[Esc]**, or, if the analyser has been switched off, switch on the power. Allow the analyser to warm up for at least 5 minutes.

2. Check that the appropriate xenon lamp has been installed in the CA 150 unit (see section 5.2.1). Switch on the lamp. The lamp must have been on for at least thirty minutes prior to the reference calibration procedure.

3. Connect the fiber-optic cables to the CB 100 setup, see the table in section 5.2.1 for the correct type. Refer to section 8 for instructions how to adjust the CB 100 setup.

4. If nitric oxide and /or ammonia (NO or NH_3) are to be reference calibrated, install the UF 220 filter in the receiving RE 060 unit.

5. Connect the fibre cable to the input on the rear panel of the analyser.

6. If required, place the measurement cell CC 001-900 in position in the calibration bench CB 100. Connect the zero air supply and set the flow rate to 500 to 1000 cc/min.

7. Make a **System check** (see section 6.2). If any of the parameters P1 to P5 is outside the permissible limits, please refer to the troubleshooting section.

8. Check the wavelength precision using the calibration lamp CA 004. Please refer to the analyser software manual, section 5.2.1, for details.

9. Enter the physical parameters for the setup in the software menus. Please refer to the analyser software manual for explanations. The sections are indicated within parentheses below.

   The offset value must be set at zero for the pollutant(s) in question, see the software manual (section 5.1.3).

   The **Cell length** should be set equal with the outside monitoring path length (section 2.3.2).

   Cell flush time should be set at zero (section 2.3.2).

   Path control should be set **Manual** (section 2.3.2). The setting at **Affected path(s)** is then insignificant.

   The temperature and pressure corrections should be set at appropriate constant values (section 2.3.2), typically 20°C and 101.3kPa.

The gas (gases) to be reference calibrated should be set **Active** (section 2.3.4).

The reference measurement time should be set 3 minutes longer than the installed monitoring time for the outside path (section 2.3.4).

Max. repetitions can be set at 2 (section 2.3.4). In case a new reference is not recorded after two trials there is either a problem with the zero air supply, the calibration lamp or the CB 100 setup, or the **New ref. limit** has been set too narrow.

The **Threshold** and the **New ref. limit** values (section 2.3.4) define the limits for the region within which a new system reference is recorded. The **Threshold** values are important when automatic calibrations are performed in order to confirm the quality of the zero air. When the recording of a new reference is activated via the keyboard the **Threshold** values could be set fairly high, 10 to 100 times the detection limit, in order to ensure acceptance of the new reference calibration. The **New ref. limit** values set the level of the desired results. As a rule of thumb, they should be set equal with the detection limit specifications for the actual monitoring path length.

- ***Example 5.1:*** A certain air quality monitoring path is 500 metres in length. The detection limit is defined to approximately 1 ppb. The **New ref. limit** values for the concentration and the standard deviation should then be set at 1 ppb. The **Threshold limit** values can be set at, for instance, 10 ppb. This means that a new reference will be recorded only when the test measurement is between 1 and 10 ppb.

- ***Example 5.2:*** A monitoring path length of about 100 metres results in a detection limit of about 5 ppb. In this case the **New ref. limit** values should be set at 5 ppb and the **Threshold limit** values at 50 ppb.

10. Proceed into the **Calibration procedures** menu. Follow the instructions given in section 5.1.2 in the Analyser software manual. The recording of a new reference is activated by pressing **[F2] Reference calibration.**

    By answering the question **Manual control?** with **[N]** the analyser will go through all active components automatically.

    When answering **[Y]** the operator is prompted to press a key prior to each new moment of the sequence.

    By pressing **[Esc]** a specific group of components can be ignored. It is also possible to terminate the entire procedure by pressing **[Esc]**.

    All actions are recorded and stored in a separate file on the analyser hard disk. The results can be reviewed in the function **View calibration results,** see the software manual section 5.1.4.

    Please note that a new reference will be recorded for all components set active in the reference calibration setup menu.

#

5.3 SPAN CALIBRATION

During dynamic calibrations, i.e. span calibrations, the accuracy of the analyser is checked by measuring a standard gas of known concentration. The instrument can then be fine-tuned by using a factor to multiply and/or increment measurement results.

The span and the offset factors are taken into account in the very last step in the evaluation as arithmetical adjustments of the calculated results and they do not affect the fundamental evaluation process. The span factor is used to adjust the instrument sensitivity and should ideally be 1.000. The offset factor is used to adjust the deviation from the zero line when measuring zero gas. Ideally it should be 0.000. The span factor has no dimension, whilst the offset factor has the same unit as defined in the **Measurement setup** menu; see the Analyser software manual, section 2.2.3.

A multipoint span calibration consists of at least six roughly equally spaced calibration points, including the zero point, covering at least 80 % of the measurement range.

Span calibration should be performed:

- After initial installation and all systems operational checks have been performed.
- After any major repairs and/or maintenance occurs.
- If the analyser's span (at 80% of the upper range limit) deviates more than ± 15% from the actual or true concentration (U.S. EPA requirement only).
- After the analyser has been moved or otherwise exposed to vibration.
- Once every third month under normal conditions.

From the physical relation on which the evaluation is based, it follows that the absorption is dependent on both the gas concentration and the monitoring path length. Physically, the light absorption for a specific component is dependent on the amount of molecules between the light source and the receiver. It is insignificant whether there is a high concentration over a short path or a low concentration over a longer path. As long as the factor (concentration C multiplied by the path length L) is constant, the light absorption will remain the same.

As a consequence, the expression (L × C) is important when calibrating the analyser. The unit is $\mu g/m^2$ or ppm × m, dependent on the selected measurement unit. The factor can be interpreted as the optical density. In order to cover the full measurement range the optical density should be in the same order of magnitude when span calibrating as when measuring the ambient air.

The relation is illustrated in the following example.

- ***Example 5.3:*** In a certain application the monitoring path length is 400 metres. The measurement range for SO2 is 0 to 500 ppb. The maximum optical density is then given by

  500 ppb × 400 metres = 200 ppm × m.

  Using a standard gas concentration of 1000 ppm, the calibration path is calculated to 0.2 metres, since

  1000 ppm × 0.2 metres = 200 ppm × m.

  By using shorter calibration paths, or by diluting the gas standard to lower concentrations, several measurement points within the measurement range are obtained.

In the example the following relation was used:

$$L \times C = L_c \times C_c. \quad [5.1]$$

L is the monitoring path length, C is the upper range limit, L_c is the calibration cell length, and C_c is the calibration gas concentration.

A multipoint span calibration of an open-path instrument can be performed

- ***either*** by varying C_c, i.e. by diluting the standard gas concentration with zero air
- ***or*** by varying L_c, i.e. by using calibration cells with different lengths.

The latter method has several advantages. The most important one is that no dilution system and no zero air supply is required, since the entire calibration is performed with one standard gas concentration only. Several sources of error, including the flow meters, can thus be excluded. The following description is therefore based on this method.

By using three calibration cells with the length ratio of approximately 1:2:4 up to eight calibration points can be obtained, since the cells can be inserted more than one at a time in the CB 100 setup. Knowing the standard gas concentration the total calibration length $L_c = L_{c1} + L_{c2} + L_{c3}$ for checking the upper range limit of the analyser is calculated from

$$L_c = L \frac{C}{C_c} \quad [5.2]$$

When span calibrating the analyser based on the former method the following should be considered. In order to obtain the test gas concentrations C_c the calibration gas concentration C_o has to be accurately diluted. A flow of zero air is added to the original gas concentration, and the mixture should be passed through a mixing chamber to insure a homogeneous concentration in the calibration cell.

The dilution ratio R must be accurately known for each calibration point. Hence the the two flow rates for the calibration gas F_O respective the zero air F_D must be accurately measured to better than 2%. To help insure accurate flow measurements, the two flowmeters should be of the same general type and one should be standardized against the other. The dilution ratio is calculated as the flow of the original concentration (Fo) divided by the total flow (Fo + FD):

$$R = \frac{F_O}{F_O + F_D}. \quad [5.3]$$

With stable, high resolution flowmeters and careful work, R should be accurate to better than 1%.

53.1 Hardware requirements

For performing a dynamic, multipoint span calibration of the opto-analyser, the following Opsis hardware is required:

- Calibration lamp CA 004.
- Calibration setup bench CB 100 and two RE 060 units.
- Calibration unit CA 150, together with power supply PS 150.
- Correct type of xenon lamp, see the table below
- Fibre-optic cable, two pieces 3 to 5 metres each, see below.
- Calibration cell CC 001-X, where X stands for length in millimetres. Appropriate lengths are calculated from equation [5.2] where the standard gas concentration C_c is known. At least 80% of the measurement range L x C should be covered. Available cell lengths are 10, 15, 40, 100,250, 500, and ***900*** mm.
- UV filter GG 400 – required only when NO2 is calibrated.
- UV filter UF 220 – required only when NO and/or NH3 is calibrated.

	SO_2, formaldehyde and others	NO_2	ozone, benzene, toluene, xylene	NO and NH_3
Opto-fibre	OF 60-S or -R	OF 60-S or -R	OF 60-S or -R	OF 60-R
Xenon lamp	Type A or B	Type A or B	Type B	Type A
UV filter GG 400	–	yes	–	–
UV filter UF 220		–	–	yes

Table 5.2

Please refer to the figures 5.2 and 5.3 for schemata of the setups.

5.3.2 Span calibration procedure

It is recommended that a good record keeping system is established by the operator. A site log book and calibration data sheets should be maintained with the instrument at the monitoring location. A sample calibration data form containing the types of information worthwhile keeping a record of is contained in fig. 5.5.

Proceed as follows:

1. Start the span calibration procedure by performing a reference calibration following the instructions given in section 5.2.2, items 1 through 10, thus including both a **System check** and a **Wavelength precision check.**

2. The span calibration is performed as a regular measurement using the ordinary measurement mode. The following parameters should be changed and defined in the software menus. Please refer to the analyser software manual for explanations. The sections are indicated within parentheses.

   Record the span and offset values for path 1 in the **Span/offset** menu. Then reset the values to 1.0 respective 0.0 (section 5.1.3).

   Change the **Station name** in the **Station setup** menu (section 2.1).

   De-activate the multiplexer (if any) in the **Measurement setup** menu. The **Multiplexer type** should be set **None** (section 2.2).

   Path length should ***not*** be changed in the **Path specifications** menu. The outside path length should be kept (section 2.2.2). This length is denoted L in the calculations.

   The temperature and pressure corrections should be set at **Constant,** and the values should be entered in accordance with the conditions inside the cells, typically 20°C and 101.3kPa (section 2.2.2). In case the cell pressure is higher than the atmospheric, the over-pressure can be determined by means of columns of water (10 cm water column = 1 kPa).

   Record the installed times in the **Measurement time** menu. Set the time for the gas in test to 30 to 60 seconds. All others should be de-activated, i.e. set at zero (section 2.2.2).

4. Connect the opto-fibre from the CB 100 setup to the analyser, see figs. 5.2 and 5.3. All calibration cells should be removed from the CB 100.

5. Enter the **Measurements** mode.

6. Let the analyser run for about 10 minutes to stabilize on the zero point. Meanwhile, connect the CC 001 cells to the calibration gas delivery system and let standard gas flow through the cells with a flow rate of 0.2 to 0.5 l/min. Make sure that the gas is vented to the outside and that there are no leaks in the system.

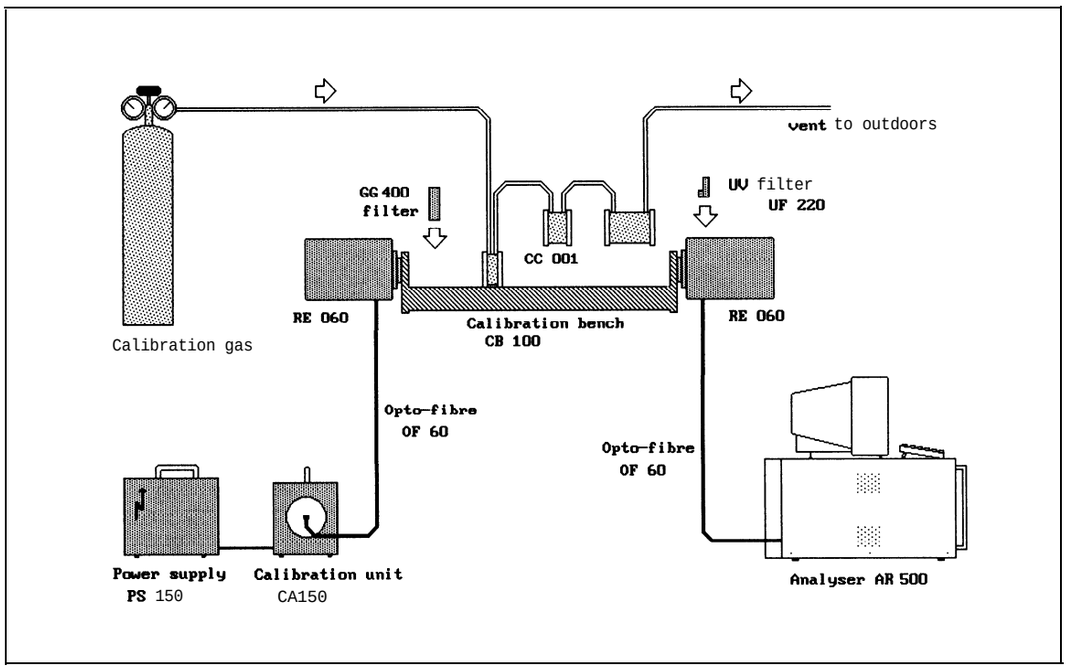


Fig. 5.2 The setup for performing a dynamic, multipoint span calibration of gases available in cylinders, such as SO_2 and NO_2.

The GG 400 filter is required for NO_2 calibrations only. It should be inserted between the light source and the first calibration cell.

The UF 220 filter should be attached inside the receiving RE 060 unit only when span calibrating NO and/or NH_3.

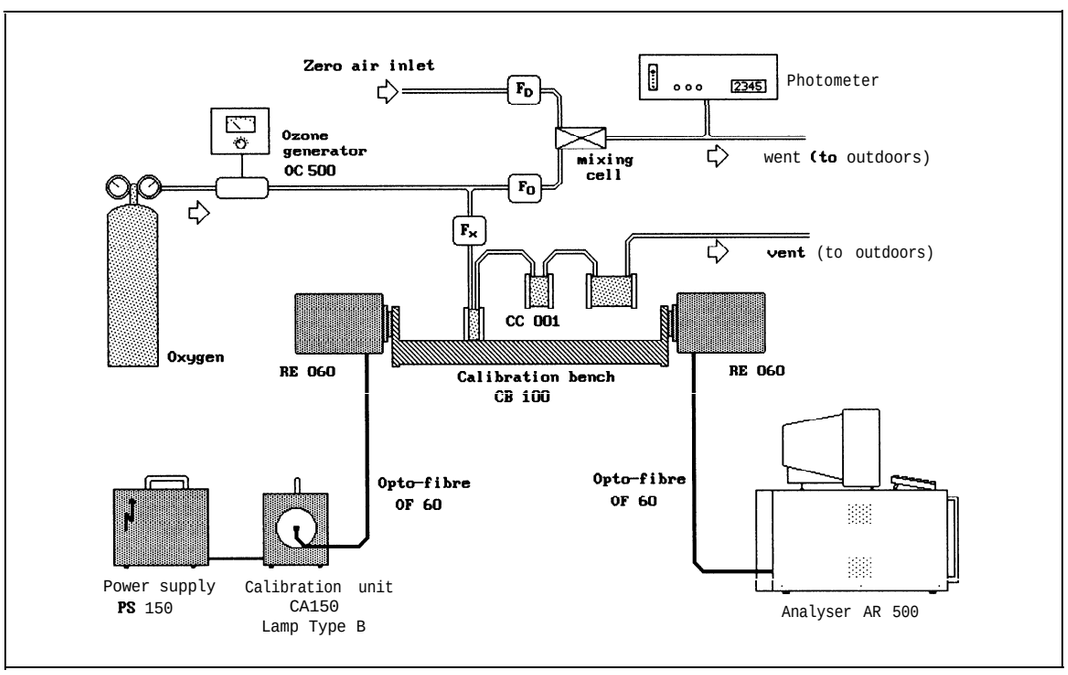


Fig 53 The ozone calibration setup based on the Opsis ozone generator OC 500. In order to dilute the ozone calibration concentrations to ambient levels for assay by the photometric instrument the flow rate ratio $F_O : F_D$ should be at least 1: 100.

The flow rate through the cell F_x is insignificant for the assay, however, it should be set between 200 and 500 cc/min.

7. If the measured zero air concentration is higher than three times the detection limit*, repeat the reference calibration procedure. Record five consecutive readings of the final zero air response and calcualte the mean value.

*) The detection limit is typically 1 ppb for most pollutants when measured over a path with length 500 metres.

8. Insert the longest CC 001 cell in the CB 100 setup. Allow 10 minutes to ensure a stable reading.

9. Perform the multipoint span check by inserting the cells in the CB 100 setup in the following sequence

L_{c1}
L_{c2}
$L_{c1} + L_{c2}$
L_{c3}
$L_{c1} + L_{c3}$
$L_{c2} + L_{c3}$
$L_{c1} + L_{c2} + L_{c3}$

Record five consecutive readings for each measurement point and calculate the mean values. The form in fig. 5.5 can be used for recording the data.

In case the test gas concentrations are generated by means of dilution, set the calibration system to deliver five upscale test gas concentrations at approximately 10, 20, 40, 60 and 80% of the measurement range. Allow at least 20 minutes for stabilization at each of the concentration levels.

10. Calculate the linear relationship values of the slope (k) of the line and the zero intercept (b) on the y-axis for measured response (Y) as a function of true test gas concentration (X); $Y = k \times X + b$.

The slope ***(k)*** should not deviate from 1.0 by more than ±20%.

The intercept value (b) should be within two times the mean of the recorded standard deviation at approximately 10 % of the measurement range level.

The variations in measurement values should be less than three times the mean of the standard deviation at each level.

The correlation coefficient (*r*) for the defined calibration relationship should be better than 0.99.

If not within these tolerances or outside the limits, first check the calibration system for possible calculation errors in true concentration values, flow measurement errors, or improper venting of the delivery system. Check analyser settings for path length, temperature and pressure values. Check the lamp type and the light level.

11. The new span and offset factors should be entered as follows:

$$\text{span factor} = \frac{1}{k}$$

$$\text{offset factor} = -b$$

12. Continue with the next gas to be calibrated, i.e. repeat the steps 2 through 11 above, or reconnect the open air path to the analyser. The following parameters then have to be reset to their respective original settings

    system name

    temperature and pressure values

    multiplexer settings

    measurement times

    Once the parameters are reset the analyser can be turned back into normal mode of operation.

#

5.3.3 How to perform the calculations

- ***Example 5.4***

In this calculation example a span and offset calibration of SO_2 is performed. The calibration is made in accordance with the steps 1 to 12 above.

- The monitoring path length L = 400 metres and the measurement range is 0 to 500 ppb.
- Three calibration cells are used, which have the lengths L_{c1} = 0.010 m, L_{c2} = 0.020 m, and L_{c3} = 0.040 m.
- The cylinder gas concentration C_c = 2500 ppm.

The following table is obtained:

Cal. cell(s)	Cal. length L_c / m	Calc. conc. $C_c' = C_c \frac{L_c}{L}$ (X) / ppb	Analyser response (Y) / ppb	Analyser stand. dev. / ppb
	0	0		
L_{c1}	0.01	62.5	64.6 08	0.5 0.7
L_{c2}	0.02	125.0	***129.0***	***0.8***
$L_{c1} + L_{c2}$	0.03	187.5	***194.7***	***0.9***
L_{c3}	***0.04***	250.0	***261.5***	***0.9***
$L_{c1} + L_{c3}$	0.05	312.5	***316.9***	***1.0***
$L_{c2} + L_{c3}$	0.06	375.0	***384.8***	***1.2***
$L_{c1} + L_{c2} + L_{c3}$	0.07	437.5	***454.2***	***1.3***

Table. 5.3 Example on span calibration data. All values in the two last columns are calculated as the averages from five consecutive instrument readings. The form in fig. 5.5 can be used for recording the data.

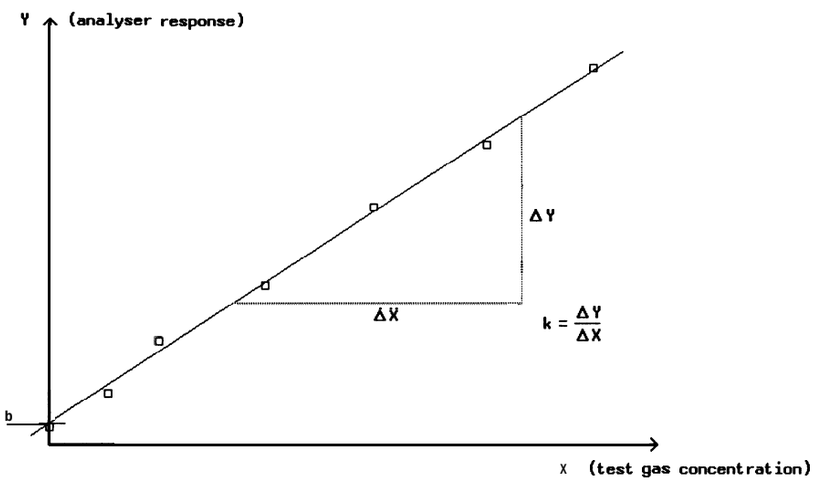


Fig. 5.4 When the data pairs are plotted in a diagram, the linear response, i.e. the slope (k) and the point of intercept of the y-axis ***(b),*** is illustrated. The correlation factor (r) indicates how well the data points are fitted to a straight line.

Many mini calculators have built-in functions for calculating the values of the slope ***(k),*** the intercept (b) and the correlation factor (I). If not, the factors can be calculated in the following way.

In the first step, the mean values $\bar{x}$ and $\bar{y}$ are calculated.

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \qquad [5.4]$$

$$\bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_i \qquad [5.5]$$

The slope is then calculated using the following formula:

$$k = \frac{\sum_{i=1}^{n} x_i \, (y_i - \bar{y})}{\sum_{i=1}^{n} x_i \, (x_i - \bar{x})} \qquad [5.6]$$

where ***n*** is the number of data pairs (here ***n = 8).***

The intercept value *b* is determined from the following relation:

$$b = \bar{y} - k\bar{x} \qquad [5.7]$$

In order to verify the linear relation the correlation factor ***r*** should be calculated; $-1 \le r \le 1$. When $r = 0$ the parameters are independent. Here, ***r*** is expected to have a value very close to 1. ***r*** is calculated through

$$r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{n - 1 \quad s_x \, s_y} \qquad [5.8]$$

where s_x and s_y are the standard deviations for the *x* values and y values, respectively.

Using the formulas above, and the readings in table 5.3, the following values can be calculated

$\bar{x}$ = 218.8 (ppb)
$\bar{y}$ = 225.8 (ppb)
k = 1.0296
b = 0.59 (ppb)
r = 0.99984

As all four conditions in step 10 above are met (assuming also the third one) the calculated values for ***k*** and ***b*** can be used to adjust the span and offset factors in the instrument.

$$\textbf{\textit{new span}} = \frac{1}{k} = \textbf{0.971} \qquad [5.9]$$

$$\textbf{\textit{new offset}} = -b = -0.6 \ (ppb) \qquad [5.10]$$

5.3.4 The calibration sample form

The calibration sample form on the next page can be used to record the results from the multipoint span calibrations. The numbers below refer to the different frames in the form.

2. In this frame the original settings are recorded as they should be reset after the calibrations are finished (all, except the span and offset values).

   Concerning the UF 220/225 filter, there is a simple rule of thumb. In case the outside measurements are made with the filter inserted in the monitoring path (i.e. installed inside the receiver RE 110/150), the calibrations should be made with a UF 220 filter.

3. In this frame the calibration parameters are recorded.

   The flow settings F_O and F_D refer to ozone calibrations only, please see figure 5.3.

4. The wavelength precision should always be checked prior to any span (and reference) calibrations.

6. The columns in the table can be used for the results in the following way.

   Cal. gas conc. is the standard gas concentration with reference to a certified cylinder or to a reference monitor response.

   Cell conc. is the the actual test gas concentration inside the CC 001 cell(s).

   When the calibration gas source is a certified cylinder the **Cell conc.** is the same as the **Cal. gas conc.**

   When a reference monitor is used to assay the test gas concentrations, for instance when span calibrating ozone, this normally has to be done after dilution down to ambient levels, see fig. 5.3. **Cal. gas conc.** is then the reference monitor response C_r, and the **Cell conc.** is calculated from the formula

$$C_c = C_r \frac{F_O + F_D}{F_O} \qquad [5.11]$$

   Please note that the formula differs from [5.3] since the calculations are here made upstreams.

   Cal. cell length is the total calibration cell length (second column in table 5.3).

   Length correction is the calculated analyser response. The ratio between the **Cal. cell length** L_C and the installed monitoring path L is taken into account (third column in table 5.3).

   Analyser response and **Standard dev.** are the mean values of five consecutive readings from the analyser.

OPSIS FIR 500

DYNAMIC CALIBRATION SHEET

Analyser S/N _____ Site location _____ Date _____

Test gas _____ Last calibration _____

2

Initial analyser data:

Monitoring path length L _____ m

Monitoring time .. _____ s

Temperature ... _____ °C

Pressure _____ kPa

Light level _____ LUX, _____ %

Span setting (existing) _____

Offset setting (existing) _____

system name _____

UF 220 / 225 ? Yes ☐ No ☐

Calibration setup data:

Cell length(s) Lc .... L_{c1} = _____ m

L_{c2} = _____ m

L_{c3} = _____ m

Monitoring time .... _____ s

Temperature _____ °C

Pressure _____ kPa

Light level _____ Lux, _____ %

System name _____

GG 400 ? Yes ☐ UF 220 ? Yes ☐

Flow settings F_O = _____ cc/m

F_D = _____ cc/m

4

Calibration lamp CA 004 test

S h i f t _____ ch.

Adjusted? Yes ☐ No ☐

Final shift _____ ch.

System check	Correction P4?	Final setting
P1 _____	Yes ☐	P1 _____
P2 _____	No ☐	P2 _____
P3 _____		P3 _____
P4 _____		P4 _____
P5 _____		P5 _____

Calibration start time _____ stop tine _____

Cal. gas conc. C / ppm	Cell conc. C_c / ppm	Cal. cell length L_c / m	(X) Length correction $C_c' = C_c \cdot \frac{L_c}{L}$ / ppb	(Y) Analyser resp./ ppb	Standard dev. / ppb

Linear regression $Y = k \cdot X + b$

k = _____ r = _____

b = _____

Final settings: Span _____

Offset _____

Fig. 5.5 Sample calibration form.

5.4 ACCURACY AUDIT AND PRECISION TESTS

Accuracy Audit and Precision tests should be performed on the analyser on a regular basis. The U.S. EPA requires accuracy audit tests to be performed once per year, and precision tests to be performed at a minimum of once every two weeks to ensure accuracy and precision of reported data. A record keeping system for test data should be established, such as plotting results on control charts.

The U.S. EPA recommends the precision and accuracy audit tests to be performed using the same light source as the open air monitoring path. Appropriate correction for the ambient concentration of the gas in test must be made at the time of the audit. The following Opsis hardware is required:

- A calibration cell CC 110 or CC 150 for mounting on the receiver RE 110 or RE 150, respectively.

The calibration cell CC 110/150 has a length of about 20 mm and a diametre of 110 respective 150 mm. It should be mounted in front of the receiver, thus replacing the original telescope window. Please refer to the ER 110 respective the ER 150 manual for instructions.

Once the cell is mounted it is recommended that two gas lines are permanently connected to the two ports on the cell. The line intended as inlet should be connected to the calibration gas generation svstem. The outlet line should be vented away from the monitoring path in order to avoid interferences with the measurements.

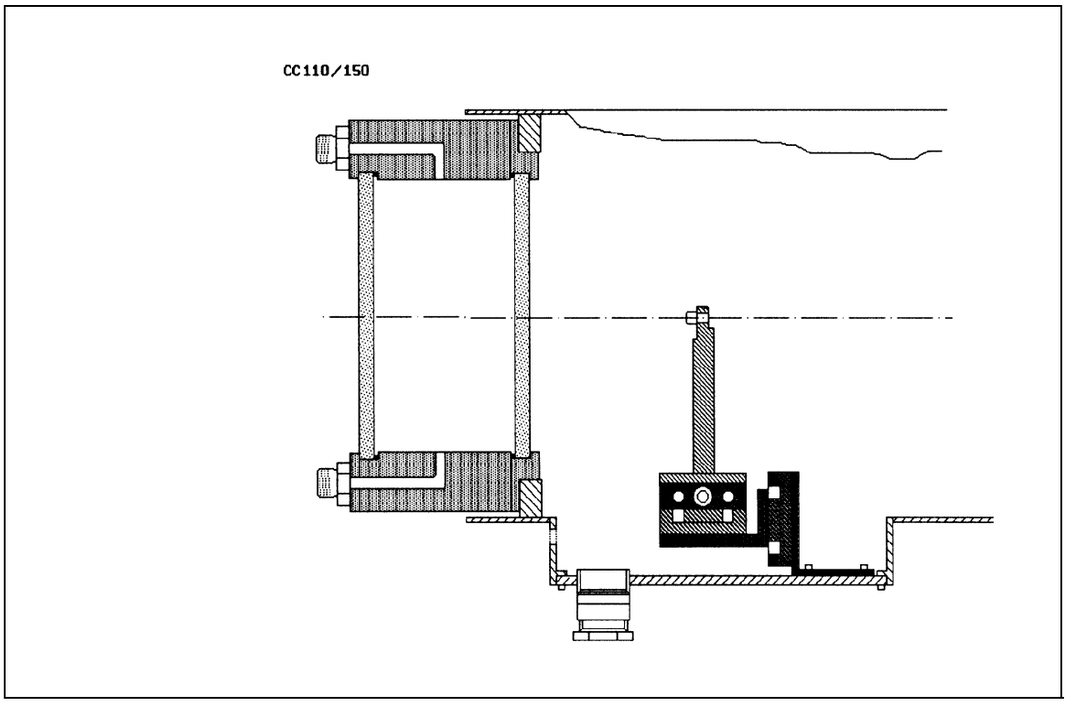


Fig. 5.6 The precision audit test cell should be mounted in the front of the receiver.

5.4.1 Test procedure

Accuracy audit tests are normally performed at several concentrations up to approximately 80% of the upper limit of the operating range. This means that an audit test gas concentration C_s of

$$C_s = C_a \frac{L}{L_c} \quad [5.12]$$

is to be used in the cell. C_a is the audit test concentration, L is the open-air monitoring path length, and L_c is the calibration cell length.

The precision tests should be performed at a low level, between 8 and 10% of the upper range limit. A precision test gas concentration C_s of about

$$C_s = C_p \frac{L}{L_c} \quad [5.13]$$

should be used, where C_p is the precision test concentration and following the same denotation for L and L_c as above.

C_s is thus the pollutant concentration inside the calibration cell which, averaged over the entire path length L, results in the effective concentration C_a respective C_p.

The tests are made by adding a well known concentration to the atmospheric background level. As a consequence pre- and post-test measurements of the background level must be taken in order to remove the atmospheric concentration contribution from the analyser response. These measurements should be taken immediately before and immediately after the tests. Although one reading may be sufficient to obtain a pre- or a post-test measurement it is strongly recommendable to record at least three consecutive readings for each measurement.

Proceed as follows:

1. The tests are performed as regular measurement using the ordinary measurement mode. The following parameters should be changed in the software menus. Please refer to the analyser software manual for explanations. The respective sections are indicated within parentheses.

   Change the **Station name** in the **Station setup** menu (section 2.1).

   De-activate the multiplexer (if any) in the **Measurement setup** menu. The **Multiplexer type** should be set **None** (section 2.2).

   Record the installed times in the **Measurement time** menu. Set the time for the gas in test to 30 to 60 seconds. All others should be de-activated, i.e. set at zero (section 2.2.2).

2. Set the calibration system to deliver a zero air flow of about 1 liter per minute.

3. Allow about 5 minutes for stabilization. Record at least three consecutive readings, calculate the average and the standard deviation (see equation [5.14] below). The average is the pre-test measurement of the atmospheric concentration.

4. Set the calibration system to deliver the audit or precision test gas concentration C_s as calculated in equation [5.12] respective [5.13]. Allow 10 minutes to stabilize. Record at least three consecutive readings, and calculate the average and the standard deviation.

5. Repeat the zero air measurement (steps 2 and 3). This is the post-test measurement.

6. Average the two zero measurements taken in steps 3 and 5 and subtract the average (i.e. the atmospheric concentration contribution) from the audit or precision test measurement taken in step 4. If the two following conditions are fulfilled the result should be reported as the audit or precision reading.

   The difference between the two averages from steps 3 and 5 must not exceed 20% of the effective concentration C_a respective C_p (EPA requirement).

   None of the standard deviations taken in steps 3, 4 or 5 should exceed 20% of the effective concentration.

   If any, or both, of the conditions are not fulfilled the result should be discarded and the test has to be repeated.

7. Flush the calibration cell with zero air for at least 10 minutes, reset the system name, the multiplexer setup, and the measurement times (if it was changed), and return to normal operation.

#

Notes.

The standard deviation s_x is calculated from the formula

$$s_x = \sqrt{\frac{1}{(n-1)} \sum_{i=1}^{n} (x_i - \bar{x})^2} \qquad [5.14]$$

where n is the number of readings, and $\bar{x}$ is the average of the n readings x_i.

The second condition in step 6 above is introduced in order to ensure that the analyser is tested during periods when the atmospheric pollutant concentrations are relatively low and steady.

5.4.2 Precision tests utilizing the CB 100 setup

An alternative setup for accuracy audit and precision test is the shown in the figure below. The light source is here the outdoor receiver used for monitoring, thus replacing the calibration unit CA 150. This setup provides the possibility to make not only multi-point span checks, but also cross sensitivity studies and similar investigations. However, as the light is taken from the outdoor path the quality of the results is strongly dependent on the circumstances. The setup is not always applicable.

The alternative setup is applicable only when sufficient light is available from the outdoor receiver. The open path must then be relatively short (less than 500 m) and the emitter/receiver units should preferably be the ER 150 type. The following rules of thumb can be helpful.

- Using the CB 100 setup for a specific component may be possible only when the received light is 300 lux, or more (when measured with Opsis light meter LM 010).
- The CB 100 must be well aligned. At least 10% of the light must be transferred. This ratio is calculated from the light intensities being measured with LM 010 after and before the CB 100 setup (I_2 / I_1 in the figure below).
- The presented light level on the screen should not read below 45 % when measuring through the CB 100 setup in order to obtain accurate results.

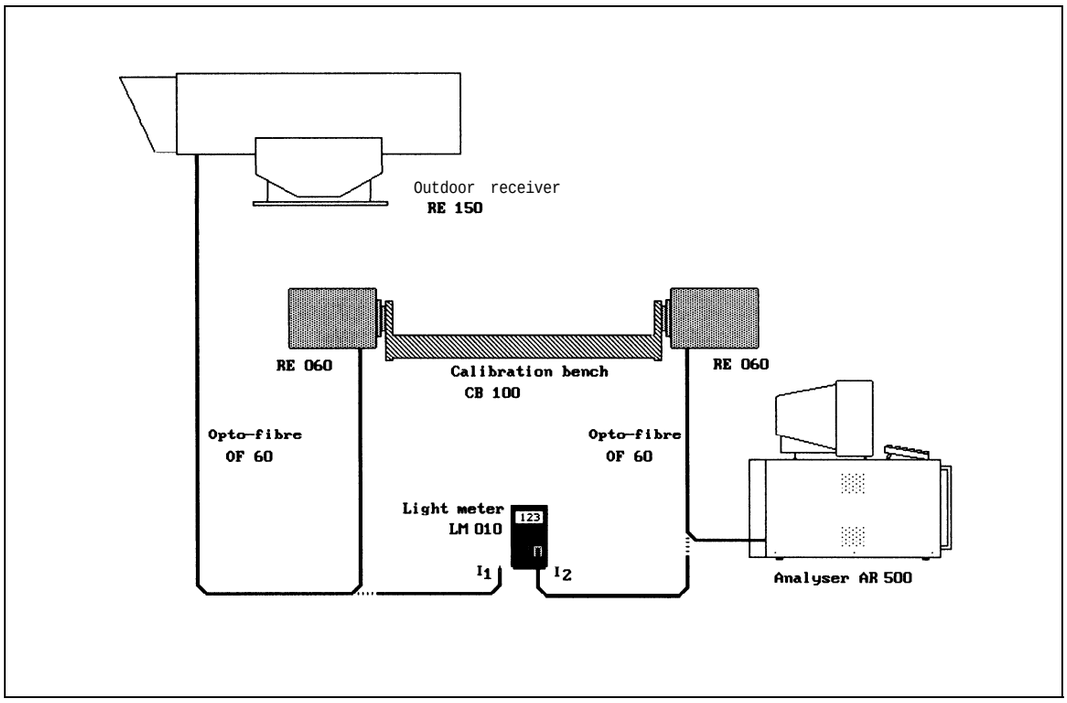


Fig. 5.7 This alternative setup for precision tests can be utilized when sufficient light is available from the outdoor receiver.

6. MAINTENANCE

Maintenance of the Opsis AR 500 system should be scheduled and followed on a regular basis to ensure proper operations and prevent the possibility of malfunctions. Maintenance records should be kept in a log book at the monitoring location.

6.1 CHECK-LIST FOR PREVENTIVE MAINTENANCE

The following actions should be taken **once a week:**

• Make a **System check.**	All five parameter values must be within their permissible limits.
• Check the recorded light levels.	If the levels have dropped, check the windows of the light path and the alignment. Clean and adjust if necessary.
• Check the standard deviations.	If the levels have increased, or they more frequently become negative, a reference calibration may be required.

Every two weeks:

- Precision test should be performed, see section 5.4 (U.S. EPA requirement).

Once per month the following should be performed:

- Reference calibration.
- Backup of data from the hard disk.
- Visual inspection of the system; the emitter, the receiver, the opto-fibre, etc.

Every third month

- Span calibration.

Once per year:

- Accuracy audit (U.S. EPA requirement).
- Examination of the complete system, including re-certification of all test gases.

6.2 SYSTEM CHECK

The **System check** is a built-in automatic hardware function check. Information is given on the function of the spectrometer and the related electronics. The results of the check are presented in the form of five numbers, and should be within specific limits to indicate proper function of the hardware.

Before carrying out the function check, study section 6 in the analyser software manual carefully. Also make sure that the fiber-optic cable is properly installed.

The type of light source is insignificant. However, the light intensity should be controlled using the **Optimize light** function at the **Installation** menu; see the analyser software manual. The presented number should be between 0.5 and 95% to ensure a proper result of the **System check.** If not, the light source should be adjusted.

Performance:

- When the light level is controlled, press **[F5], System check** in the ROOT menu. The analyser will now run for about a minute, while the hardware systems are being controlled.

- When the function check is completed, the analyser will ask **"Permanent change of P4?"**. This means that the instrument is ready for an automatic compensation of the parameter 4, P4. P4 is the only parameter which can be automatically adjusted. However, to do so the two following requirements must be fulfilled:

  parameter P3 must be within the permissible limits (see table 6.1 below).

  parameter P4 must not change significantly between two consecutive System checks.

- If parameter 4 is within the permissible limits, press **[N]**. When **[N]** is pressed the message **"System check ready. Press any key."** will be displayed. The **System check** is finished.

⇒

parameter	permissible limits
1	-150 – 150
2	3000 – 7000
3	20 – 40
4	-20 – 20
5	0.1 – loo

Table 6.1 The permissible limits for System check.

- If P4 is outside the permissible limits, and both requirements above are fulfilled, press **[Y]**. When **[Y]** is pressed, a second **System check** has to be made before P4 is adjusted by the software. If P4 has not changed significantly then press **[Y]** for yes again, and the adjustment of P4 is automatically made. Repeat the **System check** to confirm the adjustment.

NOTE: Do not UNDER ANY CIRCUMSTANCES change parameter 4 if parameter 3 is incorrect.

- If P3 is out of range, or P4 cannot be adjusted to a proper value, contact your Opsis supplier.
- If any of the parameters **P**1, P2, or **P5** is outside the permissible limits, repeat the **System check** to confirm the results. Refer to the troubleshooting section and contact your local Opsis dealer.

7. TROUBLE-SHOOTING

This section provides guidance for the determination of the causes of malfunctions or anomalies of operation as determined by check indications. The guidance is given in the form of troubleshooting trees, which may help to diagnose operating problems.

The figures describe the following problems:

Figure	Description
7.1	No power on indication
7.2	Screen remains black
7.3	Problems when monitoring
7.4	Negative deviation on some components
7.5	Negative deviation on all components
7.6	Key to System check, P1 and P2
7.7	Key to System check, P3, P4 and P5
7.8	Key to System check, P5

All checks which require the analyser cover to be removed should be performed by authorized Opsis service personnel only.

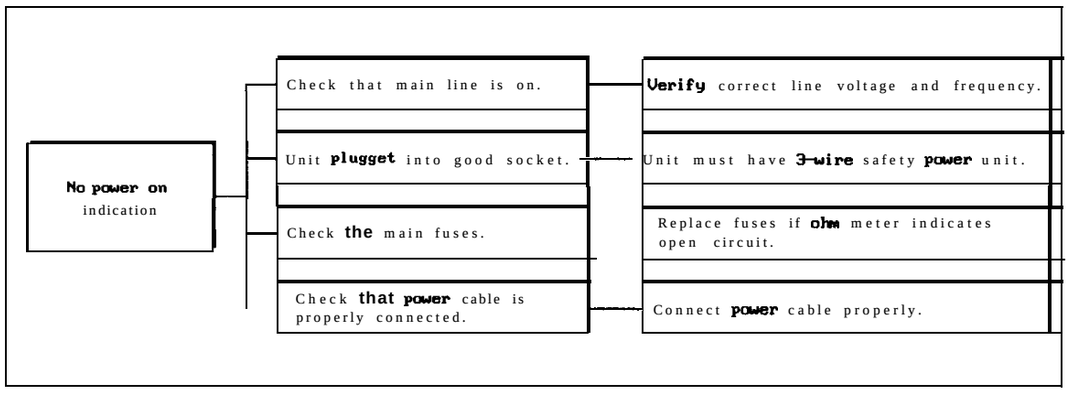


Fig. 7.1 No power on indication.

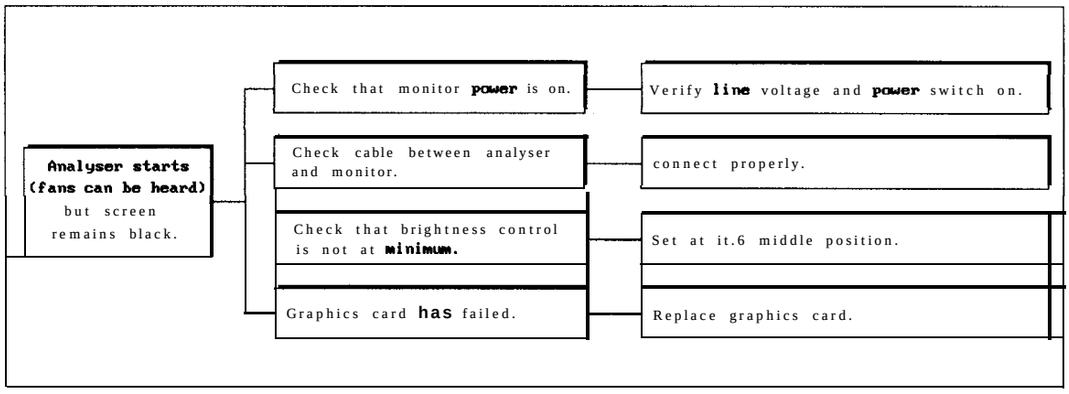


Fig. 7.2 Screen remains black.

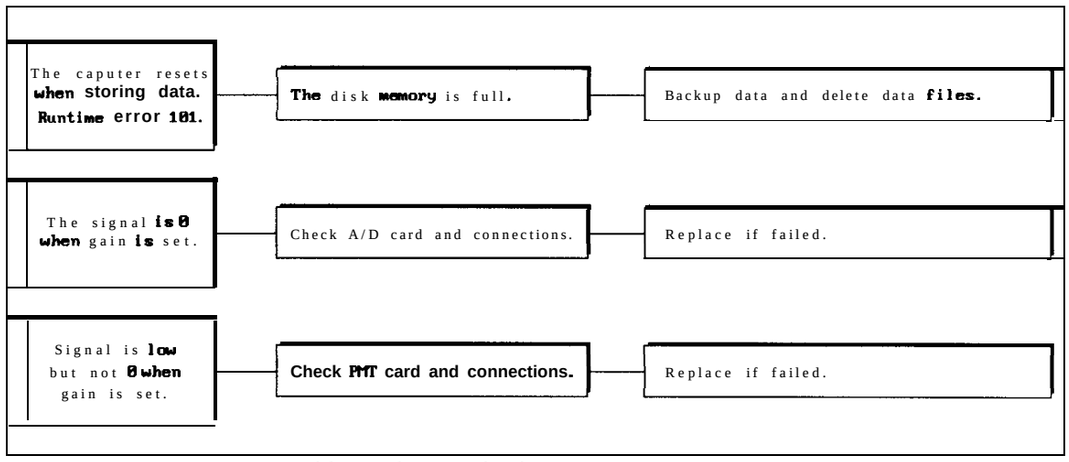


Fig. 7.3 Problems when monitoring.

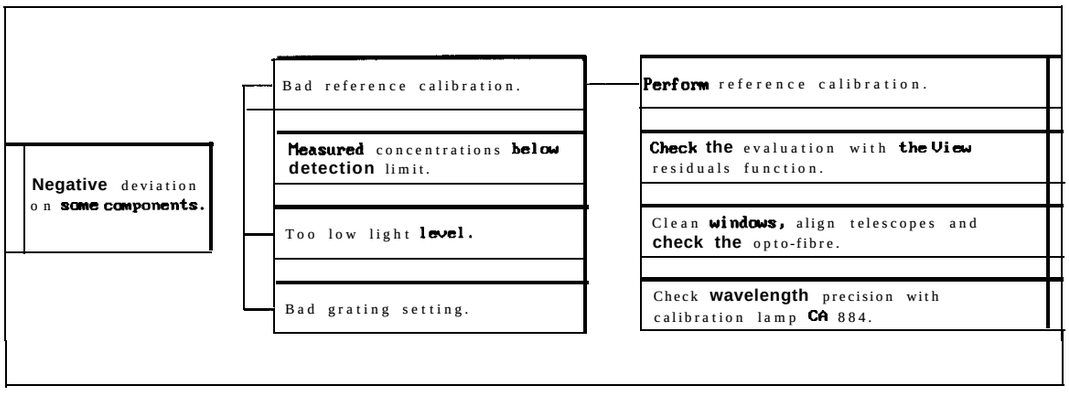


Fig. 7.4 Negative deviation on some components.

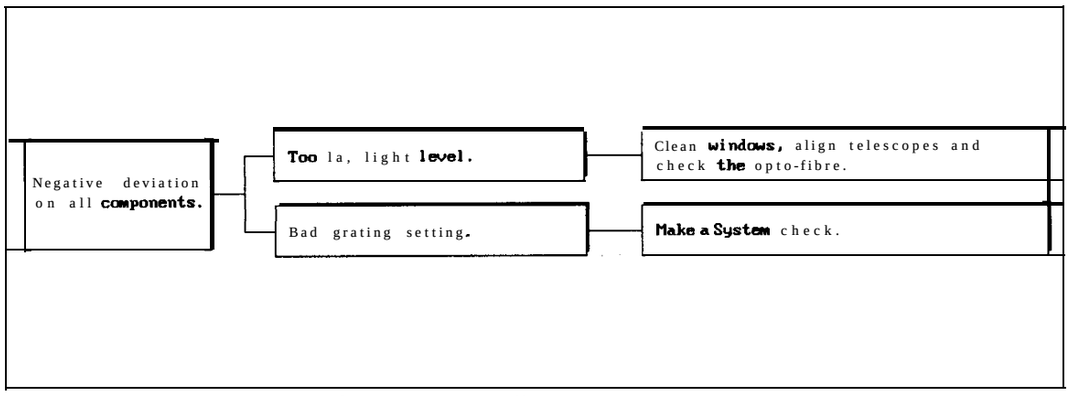


Fig. 7.5 Negative deviation on all components.

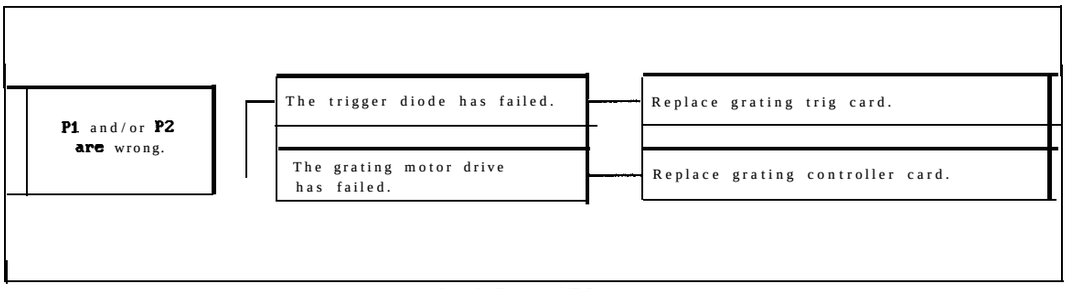


Fig. 7.6 Key to System check, P1 and P2.

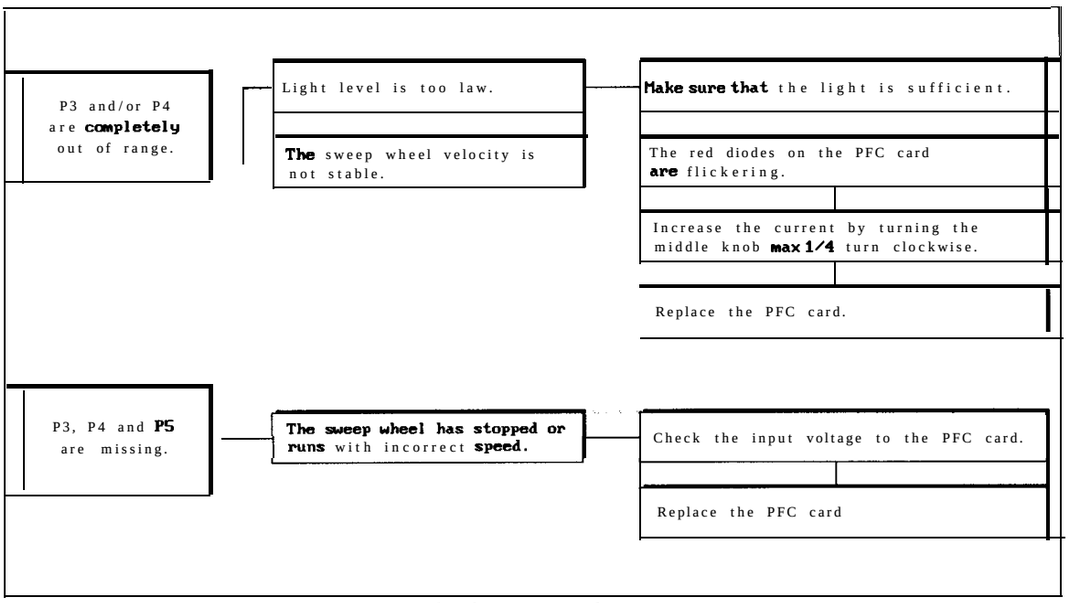


Fig. 7.7 Key to System check, P3, P4 and P5.

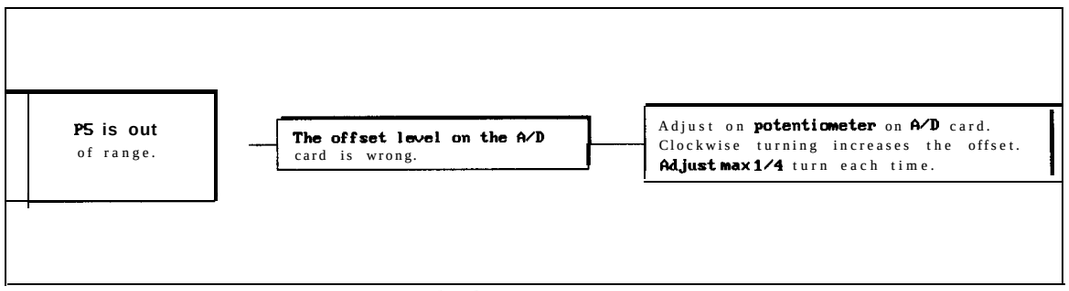


Fig. 7.8 Key to System check, P5.

8. ACCESSORIES FOR THE AR 500 SYSTEM

8.1 THE FIBRE OPTIC CABLE

Two qualities of fibre-optic cable are available for the AR 500 system. The standard cable OF 60-S is usable in most air quality monitoring applications. However, in applications where nitric oxide and/or ammonia are among the measured species the special cable OF 60-R must be used. The only difference is the extended transmission properties in the deep ultraviolet wavelength region for the special cable.

The cables are coded to facilitate identification. The OF 60-R cable has a groove turned on the nut at the terminations, see the figure below. Behind the nut there is also a red-coloured line. The standard fibre cable has neither colour identification nor groove on the nut.

The length of the fibre-optic cable is indicated behind the terminations.

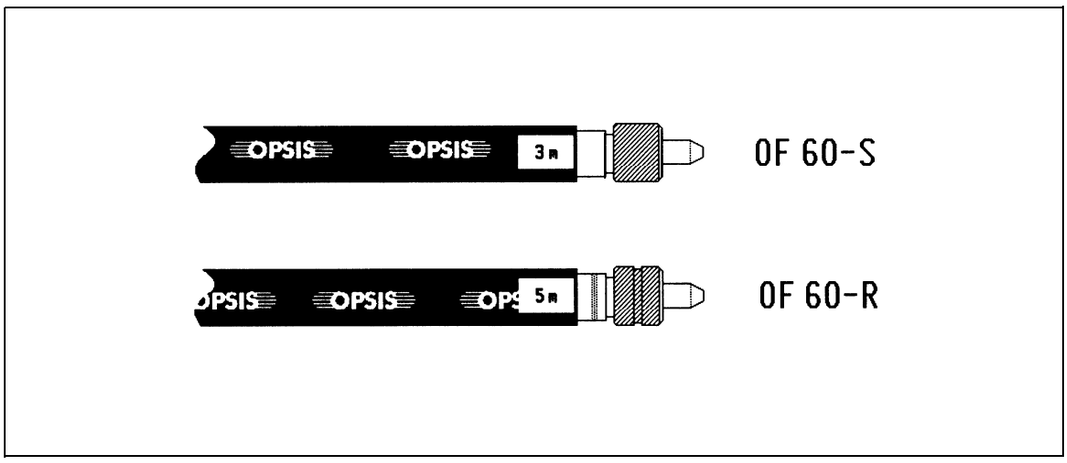


Fig. **8.1** The fibre-optic cable identification codes.

8.2 THE CALIBRATION UNIT CA 150

The calibration unit CA 150 is required for calibrating the AR 500 system (see section 5). The unit is equipped with a 150 W xenon lamp, Type B (standard), or Type A (ozone generating). The light is focused onto an optical fibre which is attached to the front plate.

For running the lamp a power supply PS 150 is required. The ignition unit for the lamp, which is attached to the CA 150 box, is described in the PS 150 manual.

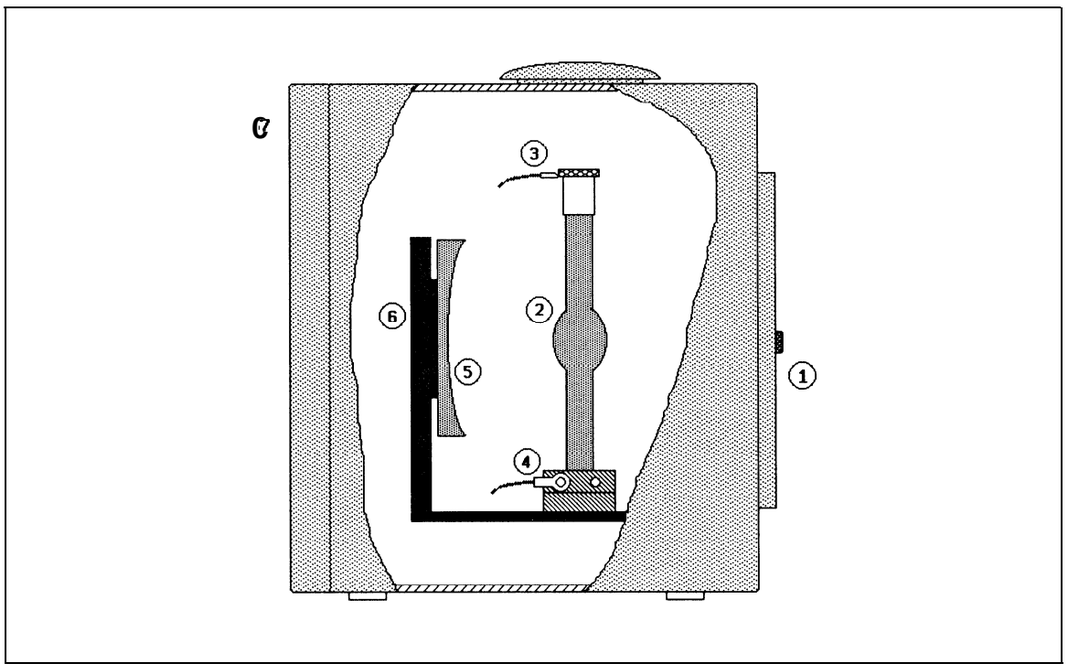


Fig. 8.2 The CA 150 unit. The ignition unit is not shown.

1. front plate with connector for fibre-optic cable
2. xenon lamp
3. cable grip nut (+)
4. fixing screws for lamp and earth cable
5. mirror, diameter 45 mm, focal length 45 mm
6. adjustment screws for mirror position
7. rear cover plate

Specifications:

dimensions	190 x 255 x 280 mm^3
material	aluminium

8.2.1 Lamp replacement

The lamp and the holder are shown in figure 8.2. The only tools required are a set of Allen keys and a screw driver.

Great care must be taken when mounting or removing the lamp. Before attempting to mount or remove a lamp, the following must be observed.

- Read through the safety regulations found in section 2.1 of the User's manual for ER 110, ER 130 or ER 150.
- Ensure that the power supply is disconnected from the mains and then disconnect the CA 150 unit from the power supply.
- Use protective glasses. Cover naked skin on hands and arms.
- Do not remove protective sheath from the lamp until absolutely necessary.
- Never touch the glass. Fingerprints will be burnt onto the glass raising the operating temperature and increasing the risk of explosion.
- The coating on the mirror is very sensitive. It must not be touched or cleaned with any liquids.

Procedure for lamp replacement (numbers in brackets refer to figure 8.2)

1. Remove the rear cover held by four screws. Unscrew the nut holding the power cable [3]. Loosen the two screws holding the lamp in place in the socket [4] and remove the lamp.
2. The new lamp is mounted in the same way as the old one. Start by transferring the protective sheath to the old lamp. Be careful to mount the lamp with the anode, marked (+), upwards. Ensure that the lamp is pushed well down into the socket. Tighten screws [4] carefully. Do not overtighten.
3. Reconnect the teflon-insulated lamp cable to the anode on top of the lamp. The nut [3] is then tightened well but carefully. If the cable shows signs of oxidation it should be cleaned before being reconnected. Ensure that the teflon-insulation is not trapped under the nut.
4. Remount the rear cover before the lamp is switched on. If the lamp has been remounted correctly the light intensity through the fibre cable will not have changed significantly.

8 . 3 THE CB 100 SETUP

The CB 100 setup is used for all reference and span calibration purposes of the AR 500 open-path system. It consists of several parts which together create a calibration path approximately 1 metre long.

Calibration light is transferred from a CA 150 unit via an optical fibre, and is collimated to a parallel beam by the emitting RE 060 unit. The second RE 060 unit captures the light beam at the opposite side of the bench, and through a second optical fibre the light is sent to the analyser.

The calibration cells CC 001-1, -10, -15, -40, -100, -250, -500, and -900, and the UV absorption filter GG 400 are easily inserted in the calibration light beam.

The cells can either be inserted one by one, or several in series. Several cells inserted at the same time enables multi-point span gas calibrations without intermediate gas dilutions, as well as cross-sensitivity checks without gas blending.

The GG 400 filter is only required when NO_2 is span calibrated.

The UF 220 filter, which is attached inside the receiving RE 060 unit, is required only when NO and/or NH_3 are calibrated.

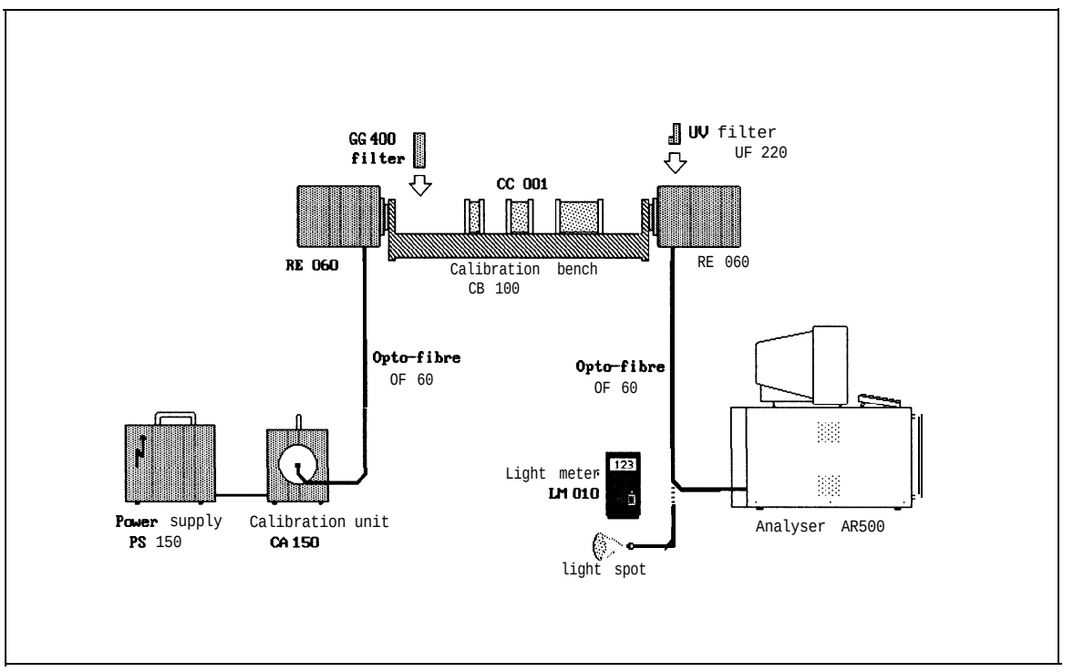


Fig. 83 The CB 100 setup.

8.3.1 The Calibration bench CB 100

The calibration bench CB 100 lines up the actual calibration path, see the figure below. Two RE 060 units are threaded onto the ends of the bench.

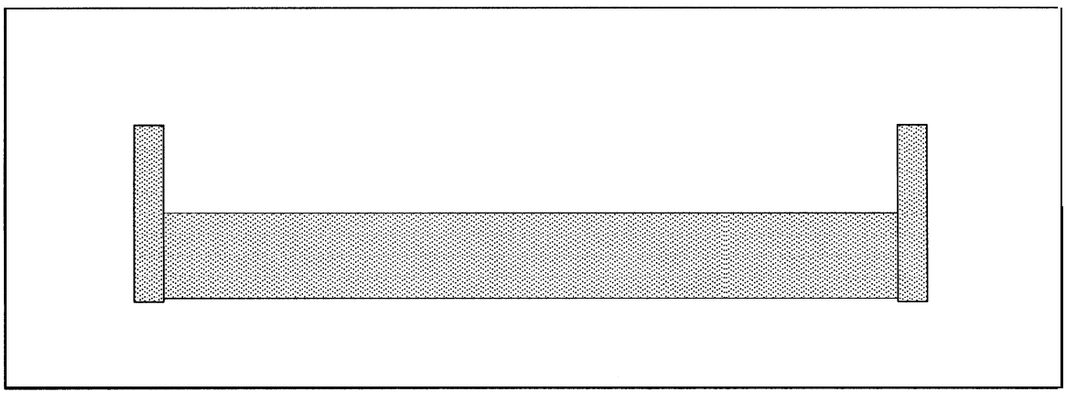


Fig. 8.4 The calibration bench CB 100

Specifications:

material	stainless steel
length	approx. 1 metre
threads	1 1/2", internal

8.3.2 The RE 060 unit

The RE 060 unit contains a fibre holder and a mirror. The optical components are adjustable for the optimization of the calibration light.

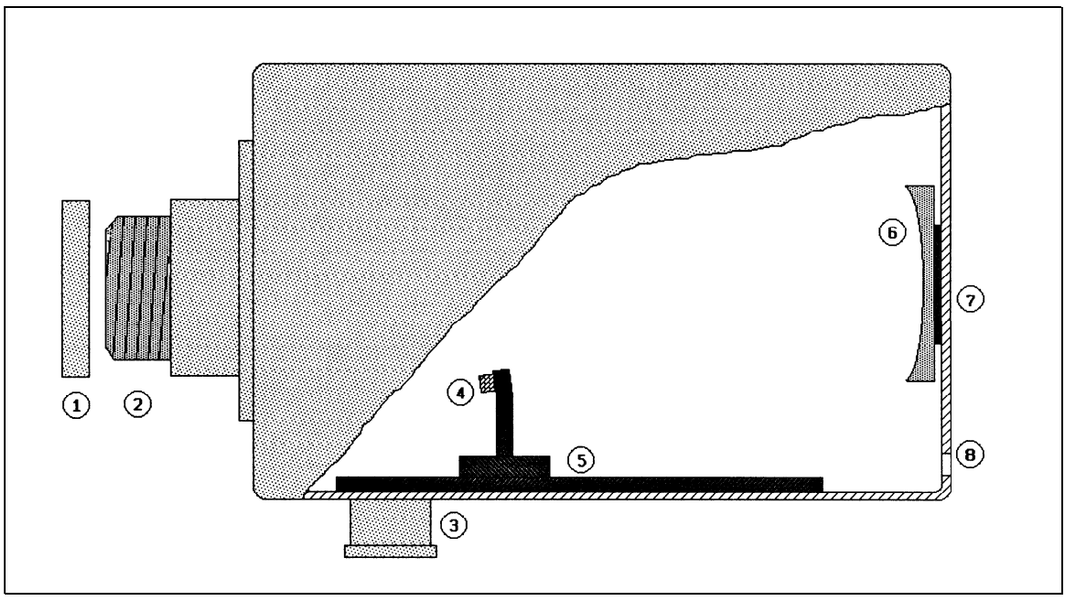


Fig. 8.5 The RE 060 unit.

1. jamb nut to enable even assembling with the CB 100 unit
2. 1 1/2" thread
3. access for optical fibre
4. threaded fibre-optic connector
5. axial adjustment screw
6. mirror
7. adjustment screws for the mirror (4)
8. access hole for the adjustment screw [5]

Specifications:

front window	quartz, Suprasil
diameter	50 mm
mirror	quartz substrate covered with aluminium and a protecting MgF_2 layer
focal length	125 mm
diameter	45 mm
dimensions	310 x 165 x 125 mm^3
material	stainless steel

Note that the coating on the mirror is very sensitive. It must not be touched or cleaned with liquids.

8.3.3 Installation of the CB 100 setup

- The two RE 060 units should be threaded onto the CB 100, one at each end. Please note that one RE 060 is marked **Emitter,** the other one **Receiver**. Use the jamb nuts so that the setup is evenly assembled.

- Switch on the power supply to the CA 150 unit, and attach the opto-fibre to the RE 060 marked **Emitter**.

- Adjust the light level on the calibration path in the following way:

  Put a piece of paper in front of the mirror in the receiving RE 060. Adjust the mirror in the emitting RE 060 using the Allen keys on the mirror adjustment screws on the rear, so that the beam is not screened off by the flanges on the CB 100. The beam on the paper should be clear and bright.

  Remove the paper. In a similar way, adjust the receiving mirror so that the light is focused in the centre of the fibre-optic connector.

  - Connect the second fibre to the receiving RE 060 and a light meter LM 010. Adjust the receiving and the emitting mirrors alternately so that a reading of 300 to 1000 lux is obtained. When removing the light meter from the fibre (see figure 8.3) the light spot from the fibre should be clear, bright and smooth. Adjust until no dark areas or halos are visible.

8.4 THE CALIBRATION CELLS CC 001

The CC 001 calibration cells are designed to be used together with the CB **100** calibration bench. All cells are provided with quartz windows and have electro-polished inside surfaces.

They are available in a number of standard lengths, see below. The exact lengths are engraved on the cells.

In order to distinguish between the different CC 001 cells the length in millimetres is added as an extension. The 40 mm cell is thus denominated CC 001-40.

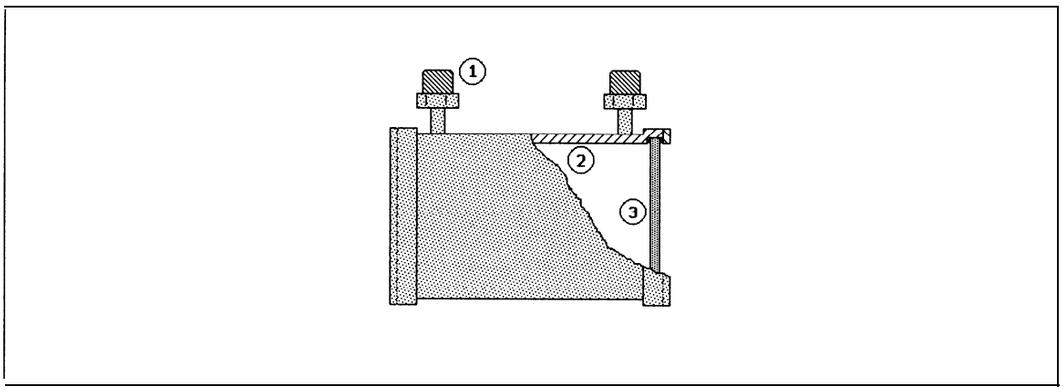


Fig. 8.6 The CC 001 cell.

1. Swagelok gas line connection
2. electro-polished surface
3. quartz window

Specifications

cell lengths	1, 10, 15, 40, 100, 250, 500, and 900 mm
inside diameter	40 mm
volumes	from approx. 3 to 1300 cm^3
windows	quartz, Suprasil 1
material	stainless steel
gas ports	Swagelok, 6 mm (1/4" optional)

8.5 THE CALIBRATION LAMP CA 004

The CA 004 calibration lamp contains a mercury fluorescent tube. The mercury lines are used to control the grating setting accuracy for the analyser in the UV range. The light is transferred to the analyser via an optical fibre.

The mercury lamp is turned on with a start button on the side of the box. The unit contains a time circuit, which automatically switches off the lamp after approximately 10 minutes.

The CA 004 unit requires 12 VDC, which is supplied from the multiplexer port on the analyser's rear panel (figure 2.1, item H).

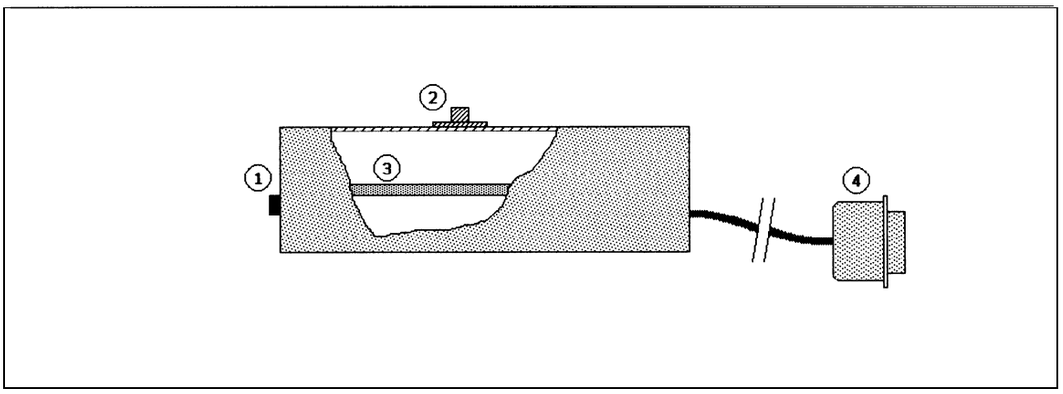


Fig. 8.7 Calibration lamp CA 004.

1. start button with power-on indication
2. threaded fibre-optic connector
3. mercury fluorescent tube
4. power connector

Specifications

lamp type	mercury fluorescent tube
input voltage	12 VDC
cable length	approx. 1 metre
connector	d-Sub 9, female
box material	aluminium
dimensions	50 x 75 x 160 mm^3

8.6 THE UV FILTER UF 220

The UV filter UF 220 is always required when reference and span calibrating nitric oxide and ammonia (NO and NH_3).

The UV filter suppresses wavelengths other than those in the region where NO and NH_3 are being evaluated. Possible stray light problems inside the spectrometer arising from the intense visible light is by those means minimized.

The UF 220 filter is easily inserted in the receiving RE 060 unit. The filter should be attached directly onto the fibre post by means of two screws on the filter holder. Make sure that no light is screened off. No other adjustments are required.

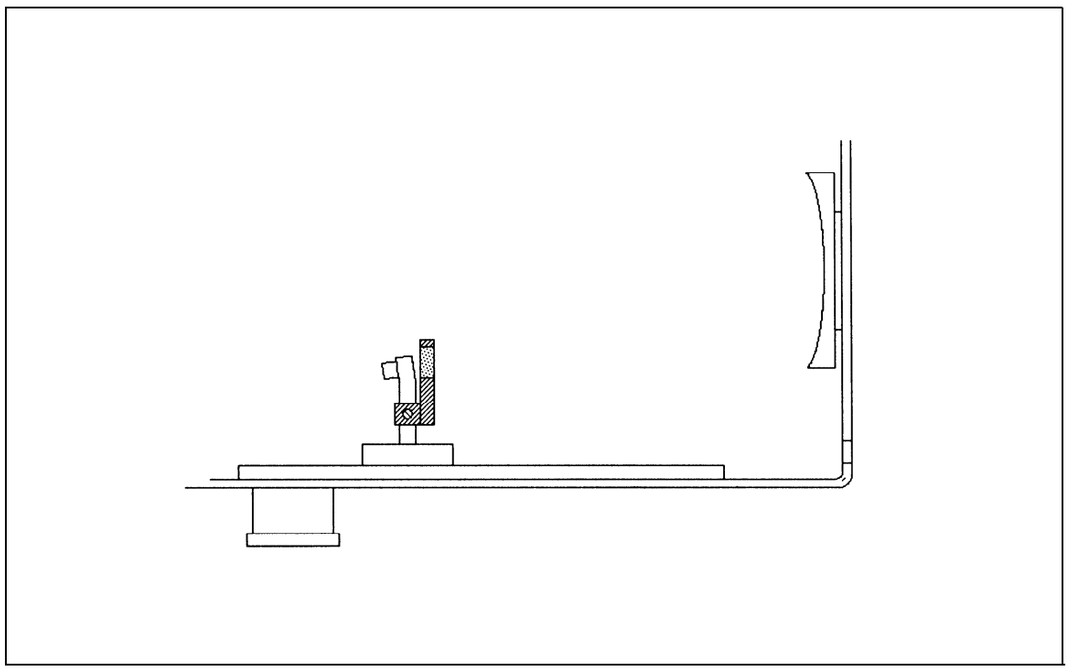


Fig. 8.8 The UV filter UF 220 inside the RE 060 unit.